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SWEET CLOVER AND THE GREY-WOODED SOILS OF THE PEACE RIVER REGION[1]

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The efficiency of power machinery in land clearing has made possible the increased use of potential agricultural land of the grey-wooded soils area. This is particularly evident in the Peace River region where future settlement will be largely confined to these soils, which comprise 78 per cent of the potentially arable land or 13,000,000 acres. Crop production on the grey-wooded soils is limited, however, by their inherent low fertility and the rapid deterioration of their physical condition under cultivation.

The experimental work reported herein was done at Beaverlodge, Alberta, where the environment is quite representative of a large portion of the region. The climate is classed as sub-humid with an average annual precipitation of 17.4 inches of which 10.3 inches are received during the growing season months from April to September. The average annual evaporation loss, computed on the basis of a free-water surface, is 18.5 inches, or approximately one-half of that reported in southeastern Alberta. The difference in evaporation can be largely accounted for by lower summer temperatures and possibly higher humidity due to natural forest cover and more free-water surfaces such as lakes and sloughs. Despite this moderate evaporation, inadequate moisture often reduces crop yields.

Evidence suggests that certain management practices which are beneficial on some grey-wooded soils of Alberta are not satisfactory in the Peace River region (6). The grey soils of the Peace are of different parent material than those farther south. Thus, the need for specific information on soil management practices under the particular soil and climatic conditions encountered in this region was apparent. Consequently, a series of experiments was initiated in 1934 to study various factors involved in the maintenance of yields. The principal objectives were to examine the possibility of substituting sweet clover for barefallow; the advisability of using no nurse-crop vs. an oat nurse-crop when establishing the clover; different methods of handling the sweet clover crop together with their interrelations with barnyard manure and commercial fertilizer.

LITERATURE REVIEW

The ameliorative effects of leguminous crops are well established (4, 9, 14, 15, 17, 25, 27), but their importance may be restricted by some limiting factor, especially moisture. Thus Barnes (3) found that the valuable

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properties of legumes cannot be fully utilized under dry-land farming in Saskatchewan. Insufficient moisture not only reduced legume growth but also prevented subsequent crops from benefiting from any increase in the nitrogen supply. Hopkins (10) reports that the moisture used by the legume more than counteracts the benefits they are supposed to afford. Ripley (23) observed a similar though much reduced relationship in the more humid parkland country bordering the great plains. On the other hand, Hopkins and Leahey (11) report that on a dark loam soil at Lacombe in central Alberta sweet clover ploughed immediately after haying, and subsequently worked as a partial fallow, gave satisfactory yields of grain the following year, although not quite so large as those after summerfallow. Wyatt *et al.* (29) in their investigations on wooded soils in a relatively humid area in central Alberta found that turning under legumes gave a stimulus to succeeding crops, but failed to advance yields over the same crops grown after summerfallow.

Wyatt (28), referring to experiments conducted on the grey-wooded soils of west central Alberta, reports that the effect of the legume on subsequent crops is not confined to yield alone but also influences quality. Thus, on these soils the protein content of wheat following clovers was substantially higher than that of wheat following wheat.

Unquestionably the greatest supply of moisture can be carried over from one year to the next by means of a summerfallow. Mathews and Cole (18) point out that, while on fallowed lands a considerable amount of the year's precipitation is lost through evaporation, this is actually small compared to the amount of water removed by growing crops. This economy of moisture, however, is only one of the benefits a fallow may offer to succeeding crops. Albrecht (1) and Newton *et al.* (20) found that fallowing released a considerable quantity of available nitrogen for ensuing crops.

Numerous trials have been conducted to discover a substitute for fallowing and thus to overcome its grave shortcomings such as sacrifice of crop, destruction of nitrogen, and reduction of fibre with the concomitant evil of soil erosion. Writing of the dry farming areas of western Canada, Hopkins (10) describes the futility of searching for a substitute for summerfallow. He mentions, however, that a partial fallow after a legume hay is quite practicable in somewhat more humid regions.

Several investigations (11, 16, 22, 26) have noted the value of ploughing down sweet clover at an early stage of growth. According to Barnes (3) the continued growth of the clover with late ploughing has a marked effect on the moisture supply.

Closely related to the question of time of ploughing down sweet clover is that of turning the entire crop under or removing a hay crop and ploughing the stubble only. Under certain conditions it has been found that the increases in yield following legumes may be as high or almost as high when the legumes are harvested as when they are used as green-manure (14). Where there is sufficient moisture in the great plains area of Canada, Hopkins and Leahey (11) are of the opinion that it is preferable to harvest the crop for hay and turn the stubble under as soon as possible thereafter, rather than plough the entire crop down for green-manure.

On newly broken land of the northwest, light applications of commercial fertilizer have been found beneficial to several crops by ensuring a supply of nutrients in the spring when soil temperatures are low. On the other hand, the advantages of barnyard manure may not be entirely realized in sub-humid regions because of moisture limitations. Wyatt *et al.* (29) found that barnyard manure, commercial fertilizer, and green-manuring, by themselves promoted wheat yields only moderately, but when either manure or fertilizer was used in conjunction with green-manuring a large increase in the yield of wheat was obtained.

PROCEDURE

One experimental plot series was laid out in each of four successive years, 1934, 1935, 1936 and 1937, on four different areas, involving approximatively 20 acres. The individual series comprised 36 treatments in duplicate. The treatments consisted of various combinations of rotations, fertilization and time of ploughing. The rotations are: Rotation I—sweet clover (seeded without a nurse-crop), sweet clover, wheat, wheat; Rotation II—oats (with a seeding of sweet clover), sweet clover, wheat, wheat; Rotation III—oats, barefallow, wheat, wheat. Rotations I and II each consisted of 16 treatments involving four methods of manuring and fertilizing (nil, good quality barnyard manure at 10 tons per acre applied in the fallow or clover year of the rotation and ploughed in; ammonium phosphate (11-48-0) at 35 pounds per acre drilled in with first- and second-year wheat; barnyard manure and ammonium phosphate) in all combinations with four methods of handling the sweet clover (green-manuring—ploughing clover before haying when the crop was two or three feet high; ploughing stubble immediately after haying; ploughing aftermath in autumn; ploughing aftermath in the following spring). Rotation III involved only the four methods of manuring and fertilizing. Plots were 165 ft. by 17.5 ft., and the harvested area per plot 145 ft. by 6.0 ft.

The experiment was continued for 11 years to provide two complete rounds of the four-course rotations in each series. The series established in 1934 was not used in the interpretation because the data from this series were incomplete.

The varieties used throughout the experiment and their seeding rates are as follows: sweet clover—Arctic, 12 pounds per acre; oats—Victory, 2.5 bushels per acre; wheat—Reward, 5 pecks per acre.

The principal factors recorded and studied are listed here according to crop. Oats—yield of bundles; sweet clover (green manure)—maturity, height, estimated yield; sweet clover (hay)—maturity, height, yield of field-cured hay; wheat (first and second crop)—maturity period, estimated per cent stand and per cent vigour in spring, summer and autumn, length of straw, yield of clean grain, grade, and protein.

RESULTS

The fact that the experimental plot series of 36 treatments were systematically arranged necessitates the application of statistical procedures to the data with considerable caution. On the other hand, the soil was extremely heterogeneous over the entire area, to such an extent that the soil characteristics of adjacent plots often appeared to possess as much

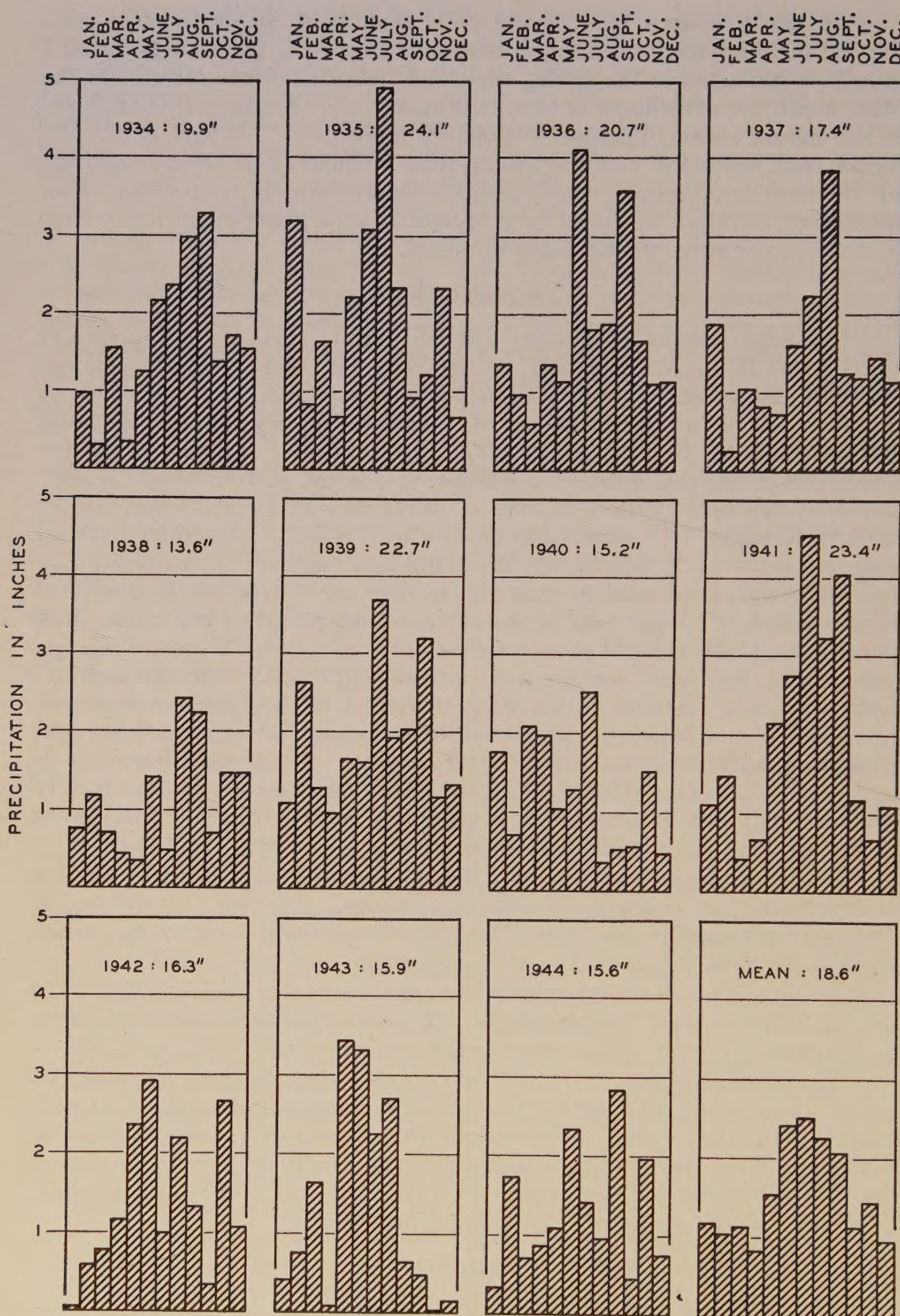

FIGURE 1. Precipitation during the experimental years, Beaverlodge, 1934-44.

differentiation as plots located farther apart. Soil differences between adjacent plots were also accentuated by the large plot size and the substantial borders (11.5) separating harvested areas and designed to avoid soil mixing. Correlation coefficients calculated for adjacent plots and for widely separated ones substantiated these observations. That is, very little systematic error was introduced into the experiment by the lack of randomization.

Effect of Precipitation and Evaporation on Wheat Yields

The importance of moisture in sub-humid regions makes it imperative that consideration be given to this factor when interpreting the effectiveness of soil treatments. Figure 1 shows that precipitation was rarely distributed as that of a "normal year".

Hopkins (13), investigating the relation of weather to wheat yields in Western Canada, found that the maximum influence of precipitation upon yield appeared to be exerted during the month of June. He attributed this effect of June rainfall to its coincidence with time of tillering of the wheat, while pointing out the close relationship between rainfall and tillering and between tillering and yield. More recently, Davis and Pallesen (5), working in North Dakota, showed that the greatest beneficial effect from rain on yield of wheat was during the rapid growth period or about three weeks before the average heading date. This period would correspond to early or mid-June in the Peace River region. They also found that the influence of rainfall rapidly diminished after heading. In North Dakota yields were significantly related with the total amount of evaporation over the season, but there were no periods during that time when the amount of evaporation proved critical.

A limited number of the correlation coefficients calculated are presented in Table 1. Examination of this table shows that the Beaverlodge results substantiate the cited observations. The yield of wheat was significantly correlated with June precipitation. As would be expected, yield was negatively correlated with June evaporation, a large proportion of this trend being accounted for by the negative relationship between precipitation and evaporation.

TABLE 1.—CORRELATION COEFFICIENTS FOR PRECIPITATION, EVAPORATION AND GRAIN YIELD FROM FIRST WHEAT CROP, 1935-1943

Factors correlated	r
Yield of Wheat—Precipitation	
Twelve months' precipitation (September to August)	0.303
Five months' precipitation (April to August)	0.293
April precipitation	0.402
May precipitation	0.338
June precipitation	0.750*
July precipitation	−0.207
August precipitation	−0.330
Yield of Wheat—Evaporation	
Four months' evaporation (May to August)	−0.692
June evaporation	−0.616
Multiple correlation—yield of wheat, June precipitation and evaporation	0.780

* Exceeds the 5 per cent level of significance.

Effect of Precipitation on Wheat Quality

The relationship between precipitation and the protein content of wheat has been studied by various workers (12, 21). Shutt (24) concluded that low-protein wheat was caused by low temperature and high soil moisture during the latter stages of kernel development. On the other hand, Hopkins (12) found that the main effect of rainfall in reducing protein content was exerted during May and June. His data did not justify the conclusion that the amount of rain falling in July or August modified the nitrogen content significantly. An investigation by Paull and Anderson (21) in the dry belt of southwestern Saskatchewan tended to substantiate Hopkins' findings. These workers found that above average rainfall during the growing season generally reduced the protein content, but this tendency was just as marked during April and early May as during time of late kernel development.

The results at Beaverlodge agree with Hopkins' conclusions but fail to support the observations of Paull and Anderson on the importance of April and early May precipitation in respect to reduced protein content. As illustrated in Table 2, protein content was not significantly correlated with rainfall received during the immediate pre-seeding and actual growing period of the wheat. The protein content was, however, negatively correlated with June precipitation.

TABLE 2.—CORRELATION COEFFICIENTS BETWEEN PER CENT PROTEIN OF WHEAT AND PRECIPITATION, 1935-1944

Period of precipitation	r
Five months' precipitation (April-August)	−0.034
April precipitation	−0.249
May precipitation	−0.228
June precipitation	−0.709*
July precipitation	0.518
August precipitation	0.326

* Exceeds the 5 per cent level of significance.

Hopkins ascribes the reduction in protein to increased tillering and vegetative development induced by June rainfall. Paull and Anderson follow much the same line of reasoning stating that increased vegetative development in June may not only depend on rainfall received in that month, but also may be stimulated by reserve moisture accumulated during the preceding April rains.

Effect of Soil Treatments on Crop Growth

Frequency distributions presented in Table 3 indicate the marked effect that the fertilizer, cultural and cropping treatments had on certain characteristics of the crops under investigation.

The distributions for the first wheat crop show a strong tendency for the various treatments to increase grain yields, as well as to reduce the protein content of the kernel and to hasten maturity. In the second wheat crop the trend toward increased yields was reduced, which can be accounted for by the fact that this crop received ammonium phosphate

TABLE 3.—THE DISTRIBUTION OF THE RESPONSES OF TREATED PLOTS IN RELATION TO THOSE OF THE UNFERTILIZED, BAREFALLOW CHECKS (SIX-YEAR AVERAGES FOR FIRST- AND SECOND-YEAR WHEAT AND THREE-YEAR AVERAGES FOR OAT HAY)

Factors	Class centres of plus or minus 1 to 6 times the standard error of a difference													Total number of plots	Mean class
	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6		
First wheat crop—															
Yield grain	—	—	—	—	—	1	5	7	7	10	5	1	—	36	+ 2.08 ± 0.24
Protein content	—	—	1	6	14	11	4	—	—	—	—	—	—	36	− 1.69 ± 0.16
Maturity	1	3	9	10	6	5	2	—	—	—	—	—	—	36	− 2.88 ± 0.24
Second wheat crop—															
Yield grain	—	—	—	—	—	1	4	17	13	1	—	—	—	36	+ 1.25 ± 0.24
Oat nurse-crop—															
Yield hay	—	—	—	—	—	2	4	3	2	5	2	1	1	20	+ 1.95 ± 0.44

only, while any influence of manure and method of clovering must have carried over from the first wheat crop. The possibility that manure and sweet clover exerted an influence on the yield of subsequent crops is demonstrated by the positive skewness of the oat hay yields.

In the interpretation of rotation experiments it is highly desirable to determine the residual effects, if any, of the various treatments involved. The data available were limited, however, to two complete rounds from each of three series, which was insufficient to definitely establish the cumulative response that might eventually accrue. In general, rounds were highly significant, but this could be largely accounted for by climatic conditions. For example, the first three wheat crops were grown during a cycle of dry seasons, while the second round sampled favourable seasons. Treatment yields within the first- and second-year wheat crops maintained their same relative positions in the three series, as expressed by the lack of significance for the interaction of treatments and series. The interaction rounds × treatments was significant for the first wheat crop, but not for the second-year wheat. This interaction could be explained on the basis of changes in magnitude of treatment yields that were not associated with changes in the relative position of the treatment means within rounds.

This situation held, with only minor variations, for all of the crops studied. Thus it was felt that the results could be most effectively dealt with by considering means computed for the entire experiment.

First Wheat Crop

Yield of Grain.—The average yield per acre of the clovered plots seeded without a nurse-crop and receiving the various cultural and fertilizer treatments was 26.2 bushels, while that of the fallowed plots was 25.9 bushels. Under the conditions of this experiment the differences encountered between these two rotations were small and non-significant. On the other hand, where the clover was grown with a nurse-crop the wheat averaged 22.7 bushels, which was significantly less than that from the barefallow plots, and again reflects a consistent trend established in the course of the experiment.

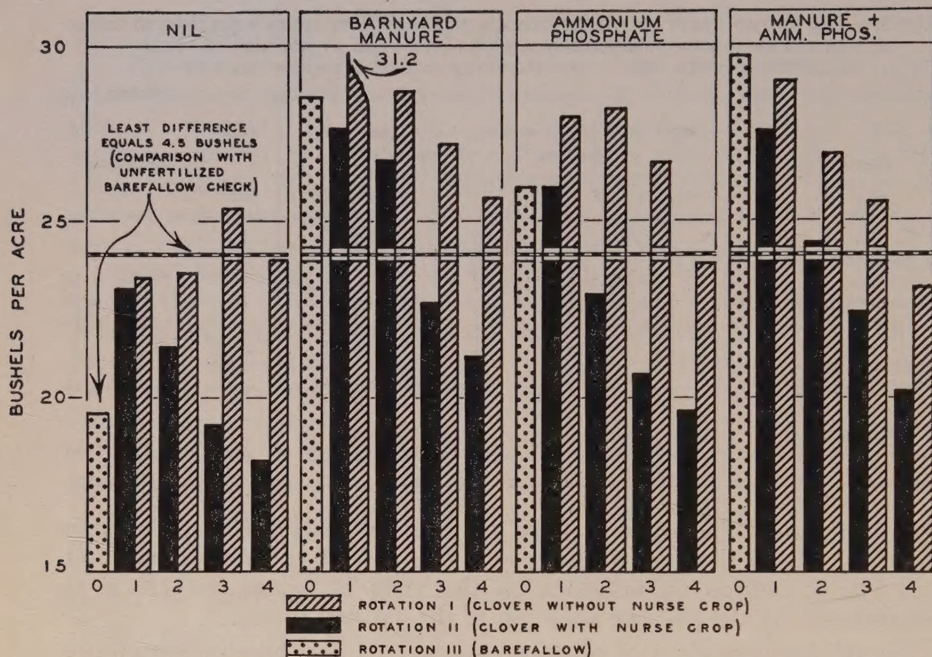

FIGURE 2. Yield of first wheat crop (six-year averages).

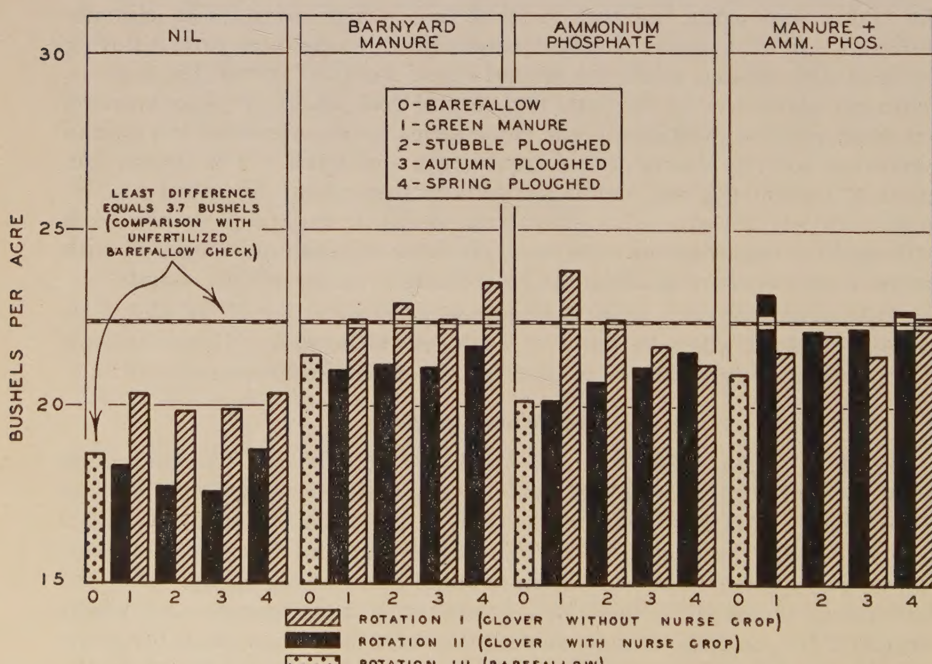

FIGURE 4. Yield of second wheat crop (six-year averages).

The deleterious effect of the oat nurse-crop is obvious from an examination of Figure 2. The reduction in yield following the nurse-crop might be due to moisture limitations, although the fact that the oats reduced the growth of clover may well contribute to this effect. Examination of the individual treatments shows a tendency for the differences between the two clover rotations to be least with the early ploughing treatments. The only discrepancy occurred when clover was stubble ploughed in combination with ammonium phosphate. It appears that the practice of seeding clover with oats may be easier to justify when the clover is either green-manured or its stubble ploughed directly after haying.

Applications of manure and ammonium phosphate, singly or together, in the barefallow rotation produced significant increases in yield over the check. No significant differences were found between the manure and ammonium phosphate or between the single and combined dressings.

In the clover rotations it is obvious that the fertilizer treatments exerted their greatest effect in combination with green-manure and stubble ploughing. Table 4 shows that spring-ploughed clover was significantly inferior to the three other cultural treatments. Green-manuring and stubble ploughing on the average of the four fertilizer treatments were not significantly different while both were superior to the autumn and the the spring ploughing treatments. All fertilizers, on the average of the

TABLE 4.—MEAN YIELDS OF FIRST WHEAT CROP (ROTATIONS I AND II)

	Yield bu. per acre
Cultural treatment—	
Green manured	26.92
Stubble ploughed	25.33
Autumn ploughed	23.69
Spring ploughed	21.94
Fertilizer treatment—	
Nil	22.23
Manure	26.35
Ammonium phosphate	24.45
Manure + ammonium phosphate	24.84

Least difference within cultural and fertilizer treatments (P .05) = 1.61 bu., (P .01) = 2.12 bu.

four cultural treatments, gave a highly significant response over the nil plots. Barnyard manure was superior to ammonium phosphate and to manure plus ammonium phosphate. Ammonium phosphate and the combined application did not differ significantly. This substantiates the field observation that grain stands were more susceptible to drought following applications of both manure and phosphate.

Protein Content.—The influence of the soil treatments on the protein content of the first wheat crop may be observed in Table 5. The difference in per cent protein between rotation I (clover without nurse-crop) and rotation III (barefallow) was not significant. In contrast, the wheat from rotation II (clover with nurse-crop) had a mean of 14.68 per cent protein

TABLE 5.—PER CENT PROTEIN OF FIRST WHEAT CROP (SIX-YEAR AVERAGE)

	Nil	Barnyard manure	Ammonium phosphate	Manure + A. P.	Mean
Rotation I (clover without nurse-crop)—					
Green manured	15.9	15.7	15.9	16.1	15.90
Stubble ploughed	15.7	15.2	15.3	15.3	15.37
Autumn ploughed	14.9	14.8	14.5	14.9	14.77
Ploughed following spring	14.6	14.9	15.5	15.2	15.05
Mean	15.27	15.15	15.30	15.37	15.27
Rotation II (clover with nurse-crop)—					
Green manured	15.3	15.1	14.9	15.3	15.15
Stubble ploughed	14.4	14.7	14.7	15.3	14.77
Autumn ploughed	14.2	14.1	14.5	14.9	14.43
Ploughed following spring	14.1	13.9	14.6	14.9	14.37
Mean	14.50	14.45	14.67	15.10	14.68
Rotation III (barefallow)	16.0	15.3	14.8	15.1	15.30

Least difference for means of fertilizer and cultural treatments within rotations I and II (P .05) = 0.46 per cent.
Least difference for fertilizer means within rotation III (P .05) = 0.90 per cent.
Least difference for comparison of rotations (P .05) = 0.23 per cent, (P .01) = 0.28.

which was a highly significant reduction from rotations I and III, 15.27 and 15.30 per cent protein, respectively. The depressing effect of the nurse-crop can be accounted for either by the lower vigour and the reduced nitrogen gathering ability of the sweet clover, or by the demands made on the available supplies of moisture and nitrogen. Both factors may be involved.

In the fallow rotation the highest percentage of protein was associated with the unfertilized check. This can be ascribed to the lush growth and increased tillering of the fertilized plots which would tend to reduce the translocation of nitrogen to the kernel (12). Another factor that might be partially responsible is the late and irregular maturity of the check plots, and the possibility that green kernels were included in the sample.

Within the clover rotations green-manuring and stubble ploughing gave consistently higher protein percentages than late ploughing. Similarly, with the majority of cultural treatments, manure plus ammonium phosphate consistently increased the per cent protein as contrasted with the nil and manure alone treatments.

As pointed out previously, leguminous crops and fallow will have an effect on the protein content of the subsequent wheat crop. The clover increases the protein content by means of nitrogen-gathering bacteria and additions of organic matter (19), while fallowing increases the availability of the nitrogen that is present in the soil (7). The time-interval which elapses between turning under the clover and sowing the wheat would also be important because of its bearing on decomposition. Thus, several factors are apparently related to the increase in per cent protein promoted by green-manuring and stubble ploughing. It would be very difficult to determine the relative importance of these factors, since in the green-manure treatment a larger amount of organic matter was ploughed under and the fallow period was longer than after stubble ploughing.

Fertilization reduced the percentage protein in the barefallow rotation, but increased the protein in the clover rotations. This apparent contradiction may be explained as follows: Applications of manure plus ammonium phosphate accentuated the effect of drought in the clover rotations but not in the barefallow rotation. The lack of moisture resulted in premature ripening which led to the production of shrunken, vitreous kernels that were relatively high in protein.

Maturity Period.—In northern areas the time required for a crop to ripen is of utmost importance. An analysis of the maturity period in the first wheat crop indicated that it was significantly affected by the soil treatments.

Table 6 shows that the average maturity period of wheat grown in rotations I and II was similar, 117.3 and 117.4 days, respectively. The average ripening period of wheat on the barefallow rotation was 118.9 days, and the added period required to reach maturity was significant. Moisture limitations in the clover rotations were probably responsible for this difference.

In the barefallow rotation manure or ammonium phosphate alone shortened the maturity period significantly, while the reduction was highly significant when they were applied together. Maturation was hastened by

TABLE 6.—MATURITY PERIOD IN DAYS FOR FIRST WHEAT CROP (SIX-YEAR AVERAGE)

	Nil	Barnyard manure	Ammonium phosphate	Manure + A. P.	Mean
Rotation I (clover without nurse-crop)—					
Green manured	119.5	119.9	120.4	117.7	119.4
Stubble ploughed	118.7	117.3	118.7	116.3	117.7
Autumn ploughed	117.8	116.1	117.3	114.7	116.5
Ploughed following spring	118.0	115.2	115.7	112.8	115.4
Mean	118.5	117.1	118.0	115.4	117.3
Rotation II (clover with nurse-crop)—					
Green manured	120.7	118.4	120.1	117.8	119.3
Stubble ploughed	119.6	117.8	118.1	115.7	117.8
Autumn ploughed	117.7	115.8	116.0	115.6	116.3
Ploughed following spring	117.9	116.6	116.3	114.8	116.4
Mean	119.0	117.1	117.6	116.0	117.4
Rotation III (barefallow)	121.3	118.1	118.6	117.7	118.9

Least difference for means of fertilizer and cultural treatments within rotations I and II (P .05) = 1.2 days.
Least difference for fertilizer means within rotation III (P .05) = 2.4 days. (P .01) = 3.2 days.
Least difference for comparison of rotations (P .05) = 0.6 day.

fertilization and by deferred ploughing in rotations I and II. Premature ripening was frequently noted on plots ploughed in the autumn or in the following spring and receiving both manure and ammonium phosphate. Droughty seasons not only promoted this premature ripening, but also reduced grain yields and increased the per cent protein.

Interrelations.—The evaluation of treatments is dependent on several factors; that is, wheat yields should be viewed in terms of protein content, maturity period, etc. Thus, correlation coefficients were calculated for a number of variables that were pertinent to the final interpretation.

Table 7 shows that a highly significant positive correlation was found for yield and protein content. This is not in accord with Harris' findings in North Dakota where heavy yields were usually associated with low protein percentage (8). Exceptions to this correlation were also observed in the Beaverlodge experiment. For instance, the untreated check plots in the fallow rotation proved high in protein despite their low yields (Figure 2 and Table 5). A similar situation occurred in the clover plots receiving both manure and ammonium phosphate, that is, above average protein was associated with somewhat lower yields. Explanations pertaining to these exceptions were offered in the section on per cent protein. In general, vigorous stands produced kernels of comparatively high protein content.

TABLE 7.—CORRELATION COEFFICIENTS FOR THE FIRST WHEAT CROP

Factors correlated	r
Yield—protein content	0.474**
Yield—maturity period	0.129
Yield—length of straw	0.681**
Protein—maturity period	0.520**
Protein—length of straw	0.453**
Protein—grade	−0.576**
(Multiple correlation) protein—yield and length of straw	0.506**
(Partial correlation) protein—length of straw, independent of yield	0.203

** Exceeds the 1 per cent level of significance.

It would seem reasonable to associate high yield with delayed maturity, especially if the latter is produced by better moisture relations. Nevertheless, the correlation coefficient for yield and maturity period was not significant. In contrast to yield, the protein content of the wheat was highly significantly correlated with delayed maturity.

The basis for these relationships can be appreciated when it is noted that the low yield of wheat produced on the unfertilized plots in the bare-fallow rotation was associated with high protein and late maturity. In the clover rotations early ploughing (green-manuring and stubble ploughing) promoted high grain yields, high protein and late maturity. Delayed ploughing lowered the yield of grain and its protein content, but hastened maturity.

A strong positive correlation existed between yield and length of straw, which suggests that under the conditions of this experiment height could serve as a rough measure of production.

The simple correlation of length of straw and protein, as well as the multiple correlation coefficient for protein, yield and length of straw were both highly significant. The non-significant partial correlation of length of straw and protein with yield held constant indicates, however, that length of straw has a limited effect on protein beyond that which can be associated with yield.

The relationship between protein content and grade of wheat is interesting from the standpoint of milling and baking. Anderson and Eva (2) found that high grade wheat drawn from the north and north-western sections of the Canadian wheat area tended, on the average, to have a slight superiority in protein content. This situation was not substantiated by Wyatt *et al.* (29) in their studies on quality of wheat from grey-wooded soils, nor was it reflected in the results of the Beaverlodge investigation where a highly significant negative correlation was established. This relationship is shown by the regression line in Figure 3.

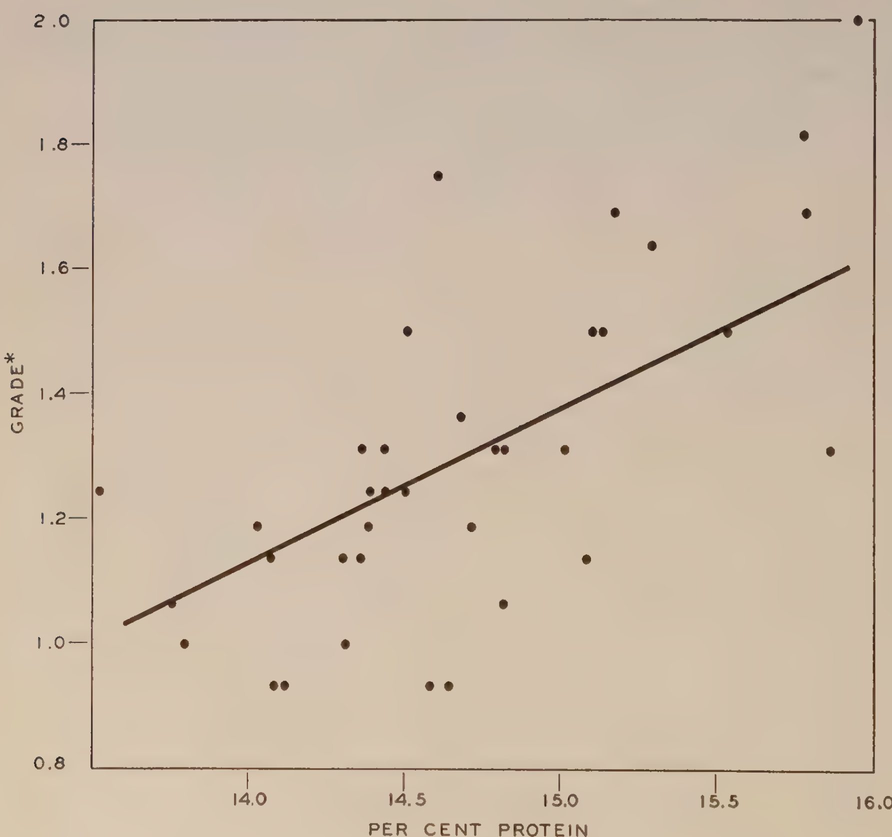

FIGURE 3. Grade : protein correlation in the first wheat crop.

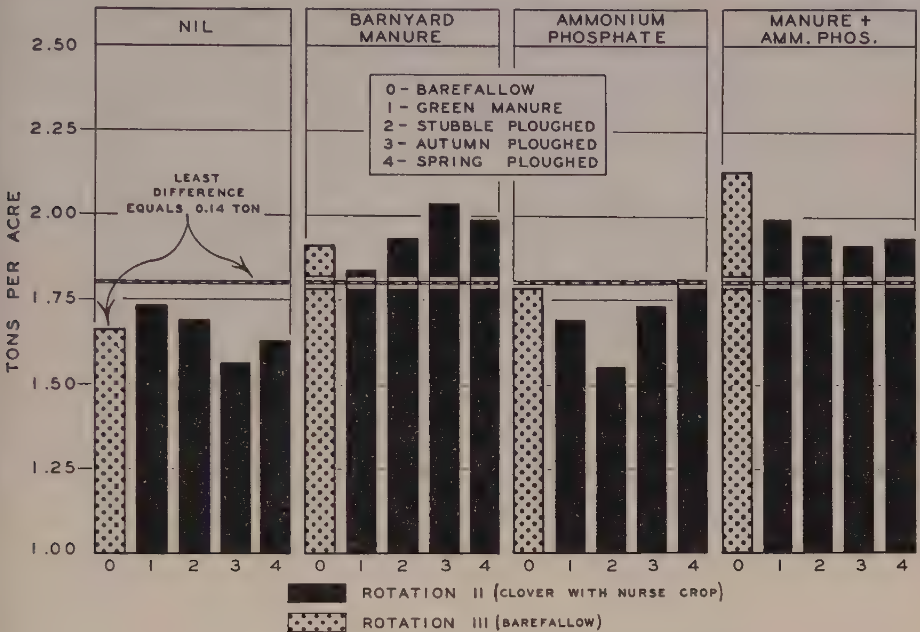

FIGURE 5. Yield of oat hay (3-year averages).

Second Wheat Crop

Analysis of the grain yields of the second wheat crop showed that, in general, soil treatments did not result in significant changes in yield. The yields levelled off considerably from those of the first wheat crop (Figures 2 and 4).

An interesting point brought out by Figure 4 is that the residual effect of barnyard manure applied two years previously rivalled that of ammonium phosphate drilled in at seeding. The impetus that manure and ammonium phosphate gave to clovering is obvious, though little additional advantage was obtained by using these fertilizers conjointly.

Oat Hay

Oat hay was used as a preparatory crop for rotations II (clover with nurse-crop) and III (barefallow). Consequently, the study of treatment effects must be confined to the second round.

Analysis of the yield data showed that the treatments were highly significant. The reason why bundle-weights of a subsequent oat crop exhibited a significant response to soil treatment is rather difficult to explain, in view of the non-significance found for second-year wheat. This could be accounted for, however, by the fact that grain yields do not measure the total response as adequately as bundle-weights.

The mean yields summarized graphically in Figure 5 serve to emphasize the importance of barnyard manure. Manure applied three years prior to the oat hay crop, either alone or in conjunction with ammonium

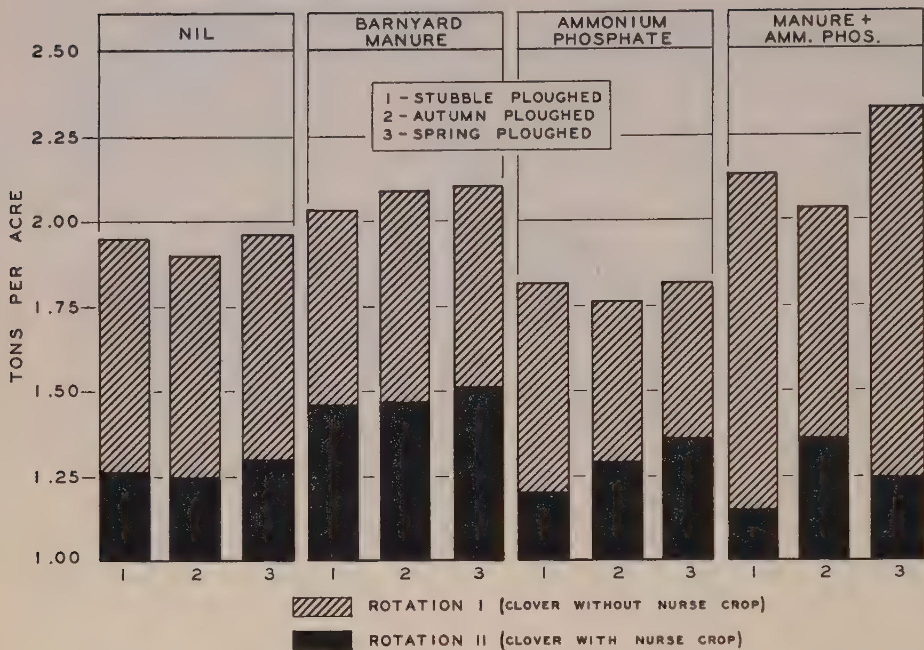

FIGURE 6. Yield of sweet clover hay (3-year averages).

phosphate, brought about significant increases in yield over plots receiving no manure or ammonium phosphate alone. Ammonium phosphate had no significant effect on yield although it had been applied to each of the two previous wheat crops.

A comparison of rotations II and III shows that the residual effect of sweet clover was of little consequence. Likewise, the method of ploughing the clover had no appreciable influence on bundle-weights.

Sweet Clover Hay

The yield of sweet clover hay from the second round of the rotation is illustrated in Figure 6. The difference between rotations I and II is very marked. Sweet clover seeded with oats yielded 1.32 tons of cured hay per acre when the four fertilizer and three ploughing treatments were averaged. When the nurse-crop was omitted this average was increased significantly to 1.99 tons of cured hay per acre.

The method of ploughing sweet clover in the first round of the rotation did not influence sweet clover yields in the second round. Slightly higher hay yields were associated with plots which had received manure four years before, while the small applications of ammonium phosphate applied with the first and second wheat had no appreciable effect.

Biological and Soil Aspects

During the course of the experiment the incidence of weeds, insects and disease were recorded, together with any effects the various treatments may have had on the soil.

Weeds.—Despite the fact that weeds were kept to a minimum by hand-pulling, they were observed to be far more prevalent wherever the clover was seeded without a nurse-crop. Delayed ploughing of the clover also favoured weed infestation.

Volunteer sweet clover approached a weed problem in the grain crops. This became more noticeable as the rotations went into their second round and was confined largely to those strips where ploughing was delayed until the autumn or the following spring. Apparently many of the lower branches of the sweet clover were missed by the mower or binder at haying and ripened seed. It is doubtful if the condition could be controlled by pasturing as these branches are often leafless and very coarse. At present the weedy tendency of sweet clover can be regarded with less apprehension in view of the availability and efficiency of 2,4-D.

Insects.—In 1938, the fifth year of the experiment, a plague of red-backed cutworms, *Euxoa ochrogaster*, stripped practically all the clover seeded without oats to the ground, killing many plants. The thinner stands in the oat nurse-crop were less severely ravaged. The attack was repeated in 1939, but damage to the clover not seeded with oats was limited to defoliation and thinning. Damage was scarcely perceptible under the oat nurse-crop.

In years when wireworms, chiefly *Ctenicera aeripennis destructor* and *Hypolithus nocturnus*, were active no relationship could be found between the injury caused by these pests and the various soil treatments.

Disease.—A rather severe outbreak of common root-rot, *Helminthosporium sativum* and *Fusarium culmorum*, reduced wheat stands in 1942. The incidence of the disease did not suggest any relationship with treatments.

Soil Effects.—After two rounds of the four-year rotations had been completed it was observed that the soil in the barefallow plots was very prone to puddle. This was especially true on plots that did not receive manure. The soil exhibited a generally poor physical condition which if of field extent might readily have washed or blown. In the clover rotations the soil structure appeared to improve.

The changes in soil structure that are indicated by these visual observations could be expected to increase in importance with time. Critical evaluation of these changes was limited by the short duration of the experiment; nevertheless, the possibility of cumulative effects either deleterious or beneficial must be considered in the interpretation of results.

SUMMARY AND CONCLUSIONS

Power machinery in land clearing has greatly increased the potential value of grey-wooded soils. This is particularly evident in the Peace River region where such soils comprise 78 per cent of the agricultural land. Improvement of these soils by the use of sweet clover in a grain rotation was investigated. Three four-year rotations were employed in which various methods of handling the clover were compared in all combinations with barnyard manure and ammonium phosphate. The experiment, comprising

some 20 acres and extending over 11 years, was conducted at the Dominion Experimental Station, Beaverlodge, Alberta. The more important findings may be briefly stated:

1. Two rounds of the rotation provided insufficient information for the determination of residual effects and an inadequate sample of the climatic variation. The occurrence of dry and wet periods extending from three to four years suggests that it would have been desirable to have sampled not less than 15 years.

2. The valuable properties of sweet clover, manure,and fertilizer were seldom wholly utilized by subsequent crops due to insufficient moisture at critical growth periods.

3. The yield of wheat and its protein content was significantly correlated with June rainfall. Rainfall during this month stimulated grain yield but decreased protein content. Precipitation at other periods was not significantly correlated with either yield or protein. The negative correlation for evaporation and yield was not significant.

4. The results indicate that sweet clover, when properly handled, may serve as a substitute for summerfallow. The yields of the two wheat crops following clover seeded without a nurse-crop were not significantly different from the yields after fallow. The per cent protein of the first wheat crop following the clover was almost the same, while the maturity period was significantly shortened. When the clover was established with an oat nurse-crop a significant though not considerable lowering of both yield and protein occurred in the first wheat crop. Moreover, the oat crop brought about a substantial reduction in the yield of sweet clover hay. To compensate for these disadvantages is the very important consideration that a fourth crop had been added to the rotation. Omitting oats would mean considerably less total production as well as poorer weed and insect control.

5. The ameliorative effect of sweet clover on the soil was evident during the first years of the experiment. This fact alone constitutes a strong argument in favour of the clover rotations.

6. No appreciable benefit was obtained by handling the sweet clover as green-manure over ploughing the stubble as soon as feasible after haying. Apparently the robust root system of sweet clover was more important than the top growth in soil improvement. Furthermore, the roots and the stubble appeared to provide as much organic material as can be successfully incorporated into the soil under sub-humid conditions. Green-manuring significantly increased the protein content of the subsequent wheat crop as compared to stubble ploughing, but delayed the maturity and lowered the grade. Ploughing the clover in the autumn or in the following spring significantly decreased the yield of the wheat crop. These later ploughings also resulted in volunteering of the sweet clover and less efficient weed control. The effect of time of ploughing the sweet clover did not carry beyond the first wheat crop.

7. Good quality barnyard manure at 10 tons per acre was superior to 35 pounds of ammonium phosphate per acre in the first crop year. Manure also induced significant yield increases in the third and fourth year after application, while ammonium phosphate, alone, significantly increased only the yield of the crop to which it was applied. No advantage

accrued through the use of manure plus ammonium phosphate over manure alone. In the clover rotations the dual application actually resulted in decreased yields most years because of insufficient moisture.

8. Under the conditions of this experiment yield of grain showed definite correlation with length of straw but not with delayed maturity. Per cent protein was positively correlated with yield of grain and delayed maturity. Grade and protein exhibited a definite inverse relationship.

9. Summarily, the results point toward the use of sweet clover, cutting it for hay, ploughing as soon as the crop can be stacked and fallowing the remainder of the season. Economic considerations appear to justify the use of a nurse-crop when establishing sweet clover. Applications of manure can be strongly recommended.

ACKNOWLEDGMENTS

Grateful thanks are extended to E. S. Archibald, Director, Experimental Farms Service, and to E. C. Stacey, Superintendent, Dominion Experimental Station, Beaverlodge, Alberta, for permission to use the data employed.

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THE CONTROL OF DOWNY MILDEW OF HOPS IN EASTERN ONTARIO[1]

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In the summer of 1944, there was a serious outbreak of downy mildew, caused by *Pseudoperonospora humuli* (Miyabe and Tak.) Wils., on hops in Prescott County in Eastern Ontario. Up to that time, the growers in this district had depended entirely on dusting, chiefly with sulphur, for the control of all fungus diseases of hops. While the dusting effectively controlled powdery mildew (*Sphaerotheca humuli* (DC.) Burr.), it had little effect on downy mildew.

From 1945 to 1948, inclusive, a series of tests with a variety of fungicides was conducted in commercial hopyards at the Illustration Station, Fournier, Ont. The purpose of the tests was to demonstrate to the growers the superiority of spraying over dusting for disease control and to develop a control program adapted to the district.

Randomized replicate plots were used in the preliminary trials of 1945 and 1946, but, when the tests were conducted on a commercial scale in 1947 and 1948, small plots were not practical, and, on account of the value of the crop, it was not feasible to leave unsprayed plots or border rows. Therefore, it has not been possible to determine statistically the degree of effectiveness of each fungicide tested. Nevertheless, a comparison of the disease incidence and the yields over the four-year period shows that the results obtained were consistent.

MATERIALS AND METHODS

In the preliminary tests of 1945, small plots, containing 16 hills and separated by two unsprayed rows, were used. The fungicides were applied by means of a small garden sprayer operated by hand. In the following year, 21-hill plots separated by unsprayed rows were used, 5 replicates for each treatment, and the sprays were applied by means of a power-driven orchard sprayer equipped with a portable spray gun. For the tests in 1947 and 1948, the spray plots consisted of 8 rows the full length of two separate hopyards instead of the small randomized plots of 1945 and 1946. All rows were sprayed, but records were taken only from the centre 4 rows of these plots. The fungicides were applied, as in the commercial yards, with an orchard sprayer equipped with two fixed nozzles, one above the other and directed upwards, on each side.

The first spray was applied each year around June 15, when the vines, having been stripped of their lower leaves and tied to poles or trellises, were from 6 to 8 feet high. Applications were repeated at 10-day intervals until the cones began to form, about August 1. Spraying was discontinued at that time to avoid staining the cones, and sulphur dust was applied thereafter when necessary to control powdery mildew.

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The spray materials tested in one or more seasons are as follows (unless otherwise specified, the figures in the formulae refer to pounds, except the last figure which represents the total volume in Imperial gallons): Bordeaux 10-10-100, Bordeaux 10-5-100, C.O.C.S. (copper oxychloride sulphate) 8-100, Cuprocide 54-y (yellow copper oxide) 2-100, zinc sulphate and lime 10-10-100, Dithane (disodium ethylene bisdithocarbamate), zinc sulphate, and lime 2 qt.-1-¾-100, and resin and lime sulphur 0.1-0.2-100.* A spreader-sticker, Orthex, was added to each mixture (except resin-lime sulphur, which is self-spreading) at the rate of 1 pint per 100 gallons. In order to determine the effect of this material on coverage, disease control, and yield, Bordeaux 10-10-100 with and without Orthex was included in the treatments.

The comparative effectiveness of the various treatments in controlling downy mildew was assessed from observations made throughout the growing season. Before the crop was harvested, the vines in each plot or section were counted. The cones from each plot were weighed as they were harvested and the fresh weight yield in pound per vine was calculated. This figure was multiplied by 3000 to derive the yield per acre corrected for stand, since a complete acre would contain 500 bearing hills and the average hill 6 vines. The fresh weight yield per acre was then converted to dry weight on the basis of 70 per cent loss in weight through curing.

RESULTS

The most satisfactory results, from the standpoints of disease control, yield, and freedom from foliage injury, were obtained with the Bordeaux mixtures and the fixed coppers. The yield data for the 1947 and the 1948 tests are shown in Table 1. It will be seen that the yields were higher in the plots sprayed with Bordeaux 10-10-100, plus the spreader-sticker, than in those sprayed with Bordeaux alone. The yields from the plots sprayed with the 10-10-100 and the 10-5-100 mixtures of Bordeaux were comparable. The highest yields in both 1947 and 1948 were obtained by the use of C.O.C.S., and the cones were of good quality.

Some of the treatments were tested only in the preliminary stages of the project for various reasons. Cuprocide 54-y gave good results in the initial trials, but was not available at the time that the full-scale tests were conducted. Zinc sulphate-lime appeared to have no advantage over Bordeaux mixture and it tended to clog the nozzles. The resin-lime sulphur mixture was abandoned because it caused serious damage to the foliage. The Dithane-zinc sulphate-lime mixture was tested only in the final year of the trials. Under the conditions prevailing in 1948, it caused some foliage injury and did not control downy mildew adequately.

SUMMARY AND CONCLUSIONS

Following an outbreak of downy mildew on hops in Eastern Ontario, a series of spray tests with various fungicides was conducted at the Illustration Station, Fournier, Ont. Spraying was found superior to dusting for the control of hop diseases, and the best results were obtained with copper

* A stock resin solution was prepared beforehand by heating together 5 parts powdered resin, 1 part KOH, and 14 parts of water, according to the directions given by Yarwood (3).

TABLE 1.—EFFECT OF VARIOUS SPRAY TREATMENTS ON THE YIELD OF HOP CONES IN 1947 AND 1948

Spray materials	Year	Yard number	Number of vines	Yield—Fresh weight		Yield—Dry weight pound per acre
				Pound per plot	Pound per vine	
Bordeaux 10-10-100	1947	1	517.0	522.0	1.01	903
		2	818.0	1034.5	1.26	1138
		Average	667.5	778.3	1.13	1021
	1948	1	418.0	370.0	0.88	658
		2	635.0	727.0	1.14	949
		Average	526.5	548.5	1.01	804
Bordeaux 10-10-100 plus spreader-sticker	1947	1	784.0	808.5	1.03	928
		2	801.0	1238.0	1.55	1390
		Average	792.5	1023.3	1.29	1159
	1948	1	462.0	350.0	0.76	647
		2	664.0	945.0	1.39	1063
		Average	563.0	647.5	1.07	855
C.O.C.S. plus spreader-sticker	1947	1	601.0	756.0	1.25	1130
		2	141.0	926.0	1.49	1345
		Average	154.5	841.0	1.37	1238
	1948	1	602.0	458.0	0.76	621
		2	758.0	1132.0	1.49	1255
		Average	680.0	795.0	1.13	938
Bordeaux 10-5-100 plus spreader-sticker	1947	1	686.0	697.0	1.01	914
		2	577.0	924.0	1.60	1440
		Average	631.5	810.5	1.31	1177

fungicides. Bordeaux mixtures 10-10-100 and 10-5-100 were equally satisfactory. It was found that the latter mixture, which is being widely used in potato spray work because of its compatibility with D.D.T., could be safely used on hops. Good disease control and high yields of good quality cones were obtained with the fixed coppers tested, C.O.C.S. and Cuprocide 54-Y. Since lime is not added to these materials, they are easy to prepare and apply.

As noted by Hoerner (1), the under-sides of hop leaves are particularly difficult to wet, owing to the presence of numerous hairs and resin glands. The addition of a spreading and adhesive agent to the spray mixtures tested at Fournier, was found to improve their initial coverage and prolong their protective effect, particularly in wet weather. The difference in spray residues between mixtures containing a spreader-sticker and those lacking it, was apparent for several weeks after the last application of the season. The cost of the spreader-sticker was very low in comparison with the value of the increase in crop resulting from its use.

The following recommendations for the control of downy mildew on hops in Eastern Ontario are based on the results obtained from the Fournier tests.

1. Spray hops at 10-day intervals in wet weather or 2-week intervals in dry weather, from the time the vines are 6 to 8 feet high (about June 15) until the cones begin to form (about August 1).* If powdery mildew appears thereafter, dust with sulphur.

2. Use a copper fungicide, either Bordeaux 10-10-100 or 10-5-100, or a fixed copper prepared according to the manufacturer's directions. Add a spreader-sticker to the spray mixture.

3. Do not depend on spraying alone to control downy mildew. Good cultural practices, including clean cultivation, early stripping and tying, removal of infected basal and lateral shoots, and destruction of crop debris after harvest, are just as important as spraying.

ACKNOWLEDGMENT

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* This schedule is comparable to that recommended by Magie (2) for conditions in New York State.

EFFECTS OF FORTY YEARS OF CROPPING UNDER IRRIGATION

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INTRODUCTION

Organized irrigation began in Alberta with the application of water to crop lands in 1901. The Dominion Experimental Station at Lethbridge was established in 1906 and immediately undertook investigations related to irrigated crop production on prairie soils. A 10-year rotation was laid down on 10 one-acre plots in 1910 and designated as Rotation "U". This experiment is located on a silty, heavy loam soil with a medium textured subsoil to a depth of 36 inches; below this level a higher percentage of fine sand is encountered. The land was broken out of native sod in 1908, following which it grew one crop of grain and was partly seeded down to alfalfa in 1909. In 1910 five plots were in grain and five in alfalfa.

Rotation "U" has been maintained on these original plots and now having completed its 40th year of production, it is believed to be the oldest continuous irrigated crop rotation in North America. In addition, it produces higher yields of cereal grains and sugar beets than any other rotation in Canada on which accurate records are available. Good husbandry methods have been used in the conduct of this rotation but there has been no special care.

This paper summarizes the yield data of the past 40 years aud attempts to interpret therefrom information having application to agricultural production under irrigation. Changes in chemical content and physical structure of the soil are discussed briefly.

OUTLINE OF EXPERIMENT

The crops of the rotation in their existing sequence, together with the fertilizer additions, average yields for the 40-year period, and yields for the crop year of 1950 are shown in Table 1.

The rotation as originally laid down included potatoes as a root crop; this was changed to sugar beets in 1923 and there have been no other variations in the crops grown. There have been some adjustments in crop sequences during the period but all crops have been grown each year and no crop failures have occurred. The original rate of barnyard manure was 12 tons per acre once in the 10-year cycle, but in 1942 this was increased to 30 tons per acre in two applications as indicated in Table 1. No commercial fertilizers were added until 1933 and since that time only the south half of each appropriate plot has received fertilizer, making available comparisons of yields from fertilized and unfertilized halves of each plot. Figures 1, 2, and 3 show these yield comparisons for some of the crops. The yield results shown in Table 1 were secured on the portions of the plots which have been fertilized chemically since 1933.

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TABLE 1.—CROPPING PLAN AND AVERAGE YIELDS FOR THE 40-YEAR PERIOD (1911-1950) AND FOR THE CROP YEAR OF 1950 FOR AN IRRIGATED CROP ROTATION ON 10 ONE-ACRE PLOTS AT THE DOMINION EXPERIMENTAL STATION—LETHBRIDGE, ALBERTA

Cropping plan and fertilization	Yields per acre*	
	40-year average	1950
First year alfalfa—100 lb. per acre 11-48-0 applied to one-half of plot	2.46	4.05
Second year alfalfa—15 tons per acre barnyard manure applied in fall	3.76	4.59
Third year alfalfa	3.70	4.56
Fourth year alfalfa—100 lb. per acre 11-48-0 applied to one-half of plot	3.69	2.73
Fifth year alfalfa	3.35	1.1[illegible]
Sixth year alfalfa—broken up in late summer	3.05	0.85
Oats	99.3	150.5
Barley—15 tons per acre barnyard manure applied to stubble in fall	65.0	87.9
Sugar beets—100 lb. per acre 11-48-0 applied to one-half of plot	16.94**	20.60
Spring wheat—seeded down to alfalfa	53.6	56.7

* Yields of grain in bushels and of alfalfa and sugar beets in tons.
** Twenty-eight-year average.

RESULTS AND DISCUSSION

Statistical Treatment of Yield Data

Statistical reduction of the yield data has been accomplished by computing the five-year average yields and showing these graphically, together with the regression lines indicating the trend in annual yields over the 40-year period.

Since the plots were not replicated it was not possible to separate out variation due to years as this was confounded with the plots of land.

The yearly yields showed considerable fluctuation, probably due mainly to seasonal effects. The five-year average yields tend to balance out and thus reduce these wide annual divergences. Regression coefficients have been calculated and regression lines drawn for annual yields of wheat and second year alfalfa over the 40-year period and for sugar beets for the 28-year period, using yields from the fertilized halves of the plots since 1933 for all three crops. In addition a similar coefficient and the resulting regression line have been shown for the yields of second year alfalfa from the unfertilized half of the plot for the 40-year period.

Discussion of Yield Results

The 40-year average yields of Table 1 present an imposing long-term record. The yields of 1950 were above the general averages with the exception of those of alfalfa in the fourth, fifth, and sixth years. These

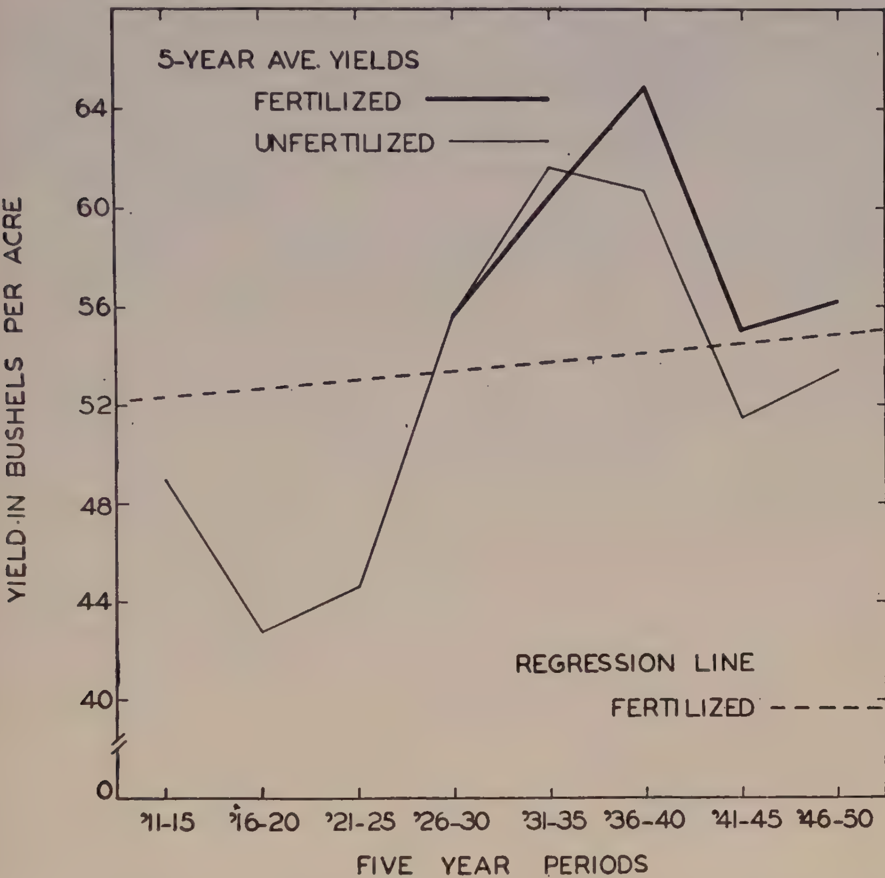

FIGURE 1. Five-year average yields of spring wheat over a 40-year period in a 10-year irrigated crop rotation together with the line showing the regression of annual yields (fertilized) on advancing years.

low yields of alfalfa were caused by bacterial wilt and crown rot diseases, which limit the economic life of alfalfa in infested fields to three or four years. Of incidental interest is the oat yield of 150.5 bushels per acre for 1950; this is the highest yield ever recorded for the rotation.

The manure and fertilizer applications account for some of the sharp changes in the various graphs and these factors are discussed in a separate section.

Wheat Yields

Figure 1 shows the average yields of wheat for the eight successive five-year periods and the line indicating the regression of annual yields on advancing years. The regression coefficient for yearly yields of wheat throughout the 40-year period was positive but of low magnitude. The calculated coefficient was, $b_{yx} = 0.09$ bushels per acre per year, whence is implied the regression of annual yields (y) on advancing years (x). The yields of wheat have been quite consistent, only three times in the

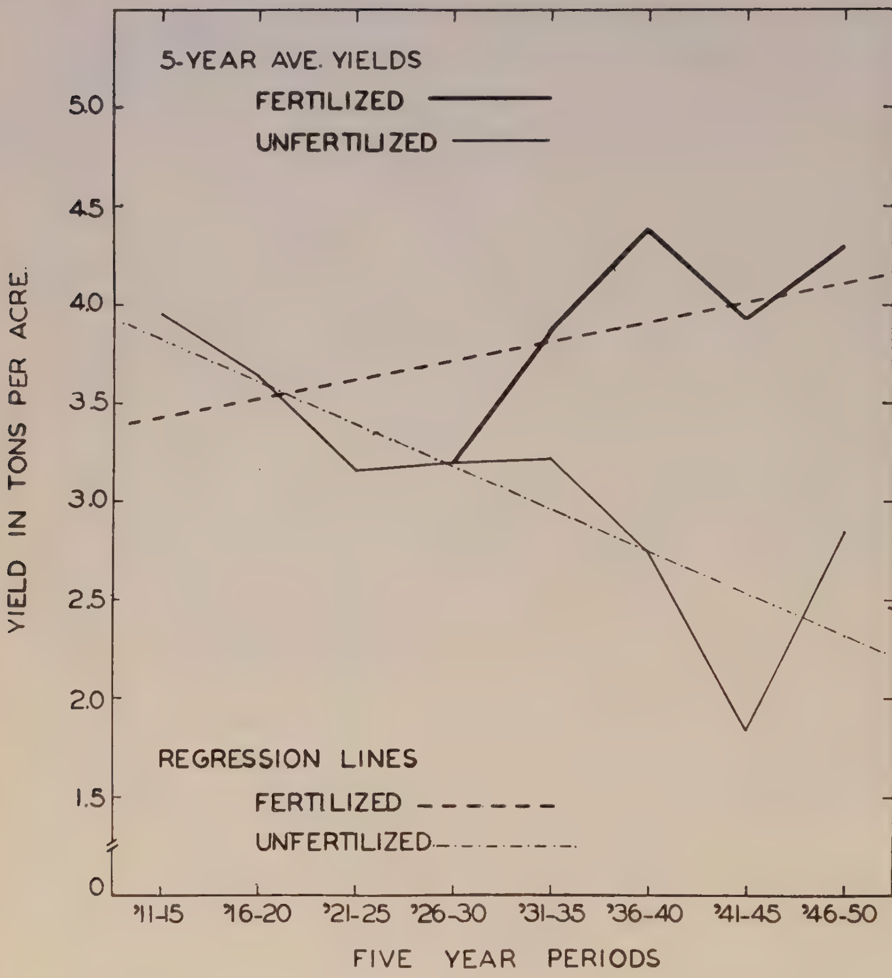

FIGURE 2. Performance of second year alfalfa over a 40-year period in a 10-year irrigated crop rotation showing the comparable 5-year average yields and regression lines for annual yields on advancing years with and without phosphate fertilizer.

40 years has the annual yield fallen below 40 bushels per acre. Since 1935 the comparative production figures on the fertilized and unfertilized halves of the plots are available (Figure 1). These have indicated a consistent superiority in yield of wheat as a result of the residual effect of the fertilizer applied elsewhere in the rotation (see Table 1).

Yields of oats and barley have shown significant, positive correlations with wheat yields.

Alfalfa Yields

The performance of alfalfa during its second year of hay production over the 40-year period is depicted in Figure 2 and has been selected as representative of alfalfa yields in this rotation.

Two regression coefficients were computed for the annual yields of second year alfalfa on advancing years. One calculation included data for the period 1911 to 1950 and made use of the yields from the fertilized halves of the plots for the period 1933 to 1950; the other calculation was similar but employed the yields from the unfertilized halves of the plots for the 1933-1950 period. Thus the annual yields from 1911 to 1932 were common to both computations.

When the data included yields from the fertilized halves of the plots the regression coefficient approached positive significance showing a value of $b_{yx} = 0.02$ tons per acre per year, while in the other case the regression coefficient was negative and highly significant, $b_{yx} = -0.04$ tons per acre per year. These values are interpreted to mean that under the existing fertilization program the yields of alfalfa have shown a slight upward trend but without the application of phosphate fertilizer the yields have retrogressed significantly.

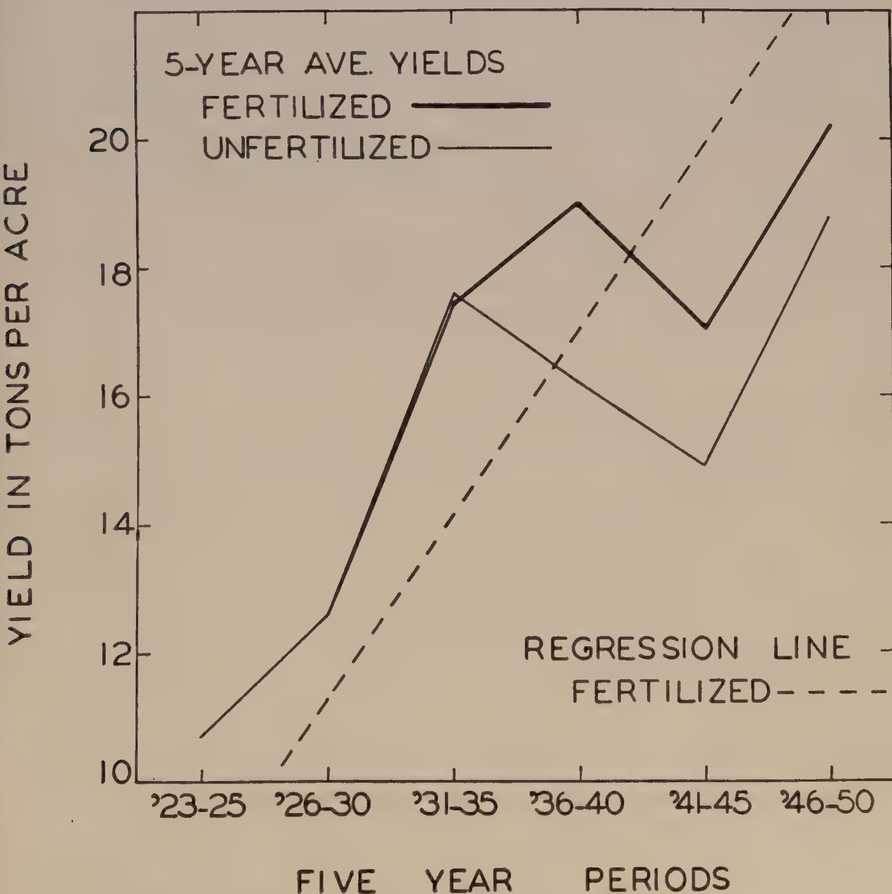

FIGURE 3. Five-year average yields of sugar beets over a 28-year period in a 10-year irrigated crop rotation together with the line showing the regression of annual yields (fertilized) on advancing years.

Sugar Beet Yields

Figure 3 shows the average sugar beet yields for the first 3 years of production and for 5 succeeding 5-year periods.

The annual yields showed a significant, positive regression coefficient of 0.57 tons per acre per year. It is thought that the decided increase in yield over the 28-year period resulted largely from improved methods of sugar beet husbandry under Alberta conditions as well as the use of better adapted varieties as the years progressed. Improved fertility since the increase in rate of manure application in 1942 likely is an additional factor. The low average yield for the 1941-1945 period was contributed to by a very dry spring in 1943, and a wireworm infestation in 1945 which made it necessary to reseed at a late date.

The addition of 100 lb. of 11-48-0 per acre to one-half of the plot regularly has increased the yields of beets over that of the unfertilized half, even though the whole plot had received an application of barnyard manure in the fall previous to growing the beet crop. The comparable average yields for the 18-year period (1933-1950) are: fertilized—18.80 tons per acre; and unfertilized—16.52 tons per acre.

Influence of Phosphate Fertilizer

During the second decade of the rotation the yields of alfalfa began to decline, presumably due to a deficiency of phosphorus. Beginning in 1933 phosphate fertilizer* at the rate of 100 lb. per acre was added to one-half of each appropriate plot three times in the rotation cycle (see Table 1). The decline in yield previous to 1933 and the increase after that date is evident from Figure 2 and indicates that a deficiency of phosphorus was the cause of the decreased yields. Sugar beets did not show a similar decline, probably because the manure applied for this crop supplied sufficient phosphorus.

Although the phosphate fertilizer has been applied only to the sugar beet and alfalfa crops, a beneficial residual effect has been evident in the yields of cereal grains; this is indicated in Figure 1 and by the following average yields (1933-1950) of oats and barley on the fertilized and unfertilized halves of the plots, respectively: oats, 107.2 and 103.2 bushels per acre, and barley, 73.5 and 71.7 bushels per acre.

Calculations made in 1950 indicate that, on the basis of present yields and additions of manure and commercial fertilizer, the phosphorus content of the soil should be maintained or enhanced.

Influence of Barnyard Manure

For the first three cycles of this rotation each plot received 12 tons of manure per acre once during each 10 years. This amount of manure supplemented by 300 pounds per acre of phosphate fertilizer applied after 1933 brought about a general increase in production. However, declining yields, beginning a few years later, indicated a general reduction in fertility. This trend reached its lowest point in the 1941-1945 period as is very apparent in Figures 1, 2, and 3. Therefore in 1942 the manurial rate was increased to 30 tons per acre per cycle, in two applications—15 tons on the

* Triple superphosphate (0-43-0) was used from 1933 to 1937 and was replaced by ammonium phosphate (11-48-0) in 1938.

barley stubble in the fall previous to the sugar beet crop, and 15 tons on the alfalfa in the fall of its second year of hay production. It should be pointed out that the influence of this additional manure would not be operative on the second year of alfalfa until the 1946 season, since in this year second-year alfalfa occurred on the plot which received 15 tons of manure in 1942 on the barley stubble. The upswing in yield of alfalfa due to additional manure since 1946 will be noted in Figure 2. Certain extenuating factors, discussed above, kept the yield of sugar beets low in the 1941-1945 period despite the effect of additional manure beginning in 1943 but the upward trend since 1946 (Figure 3) is thought to be associated with the increased manurial application.

The increases in average yield from the 1941-1945 period to the 1946-1950 period were greater on the unfertilized than the fertilized halves of the plots. This is indicated by the difference in slope of the appropriate legs of the respective lines in Figures 1, 2, and 3. Obviously manure was more efficacious on the unfertilized halves of the plots.

Chemical Analyses of Soil

The surface six inches of soil on Rotation "U" has been chemically analysed by Shutt (3) in 1910, by Caldwell *et al.* (1) in 1938, and by the Chemistry Division, Science Service, Ottawa (2) in 1922 and 1940. Further analyses were made on samples taken in 1950. The results of these studies are summarized in Table 2.

TABLE 2.—SUMMARY OF PERIODIC CHEMICAL ANALYSES OF SURFACE SIX INCHES OF SOIL FROM A 10-YEAR IRRIGATED CROP ROTATION AT THE DOMINION EXPERIMENTAL STATION—LETHBRIDGE, ALBERTA

Year	Per cent nitrogen	Per cent organic matter	Year	Per cent nitrogen	Per cent organic matter
1910	0.178	4.62	1940	0.208	3.73*
1922	0.189	4.88	1950	0.203	3.50

* 1938 analysis by Caldwell *et al.* (1).

Nitrogen

The data in Table 2 established that there has been an increase in the total percentage of nitrogen since analyses first were made in 1910. Definite improvements are apparent from 1910 to 1922 and from 1922 to 1940. The figure of 0.203 per cent for 1950 probably is not significantly different from that of 0.208 per cent recorded for 1940 and indicates that the percentage of nitrogen in the plots of this rotation may be levelling off. However, it is important to note that the manurial and cropping practices of this rotation have maintained the nitrogen content even though large quantities of this element have been removed by the crops.

Organic Matter

The organic matter content of the soil has declined since 1922. In 1950, five Rotation "U" plots showed an average organic matter content of 3.50 per cent as compared to 4.69 per cent for the sod strip bordering

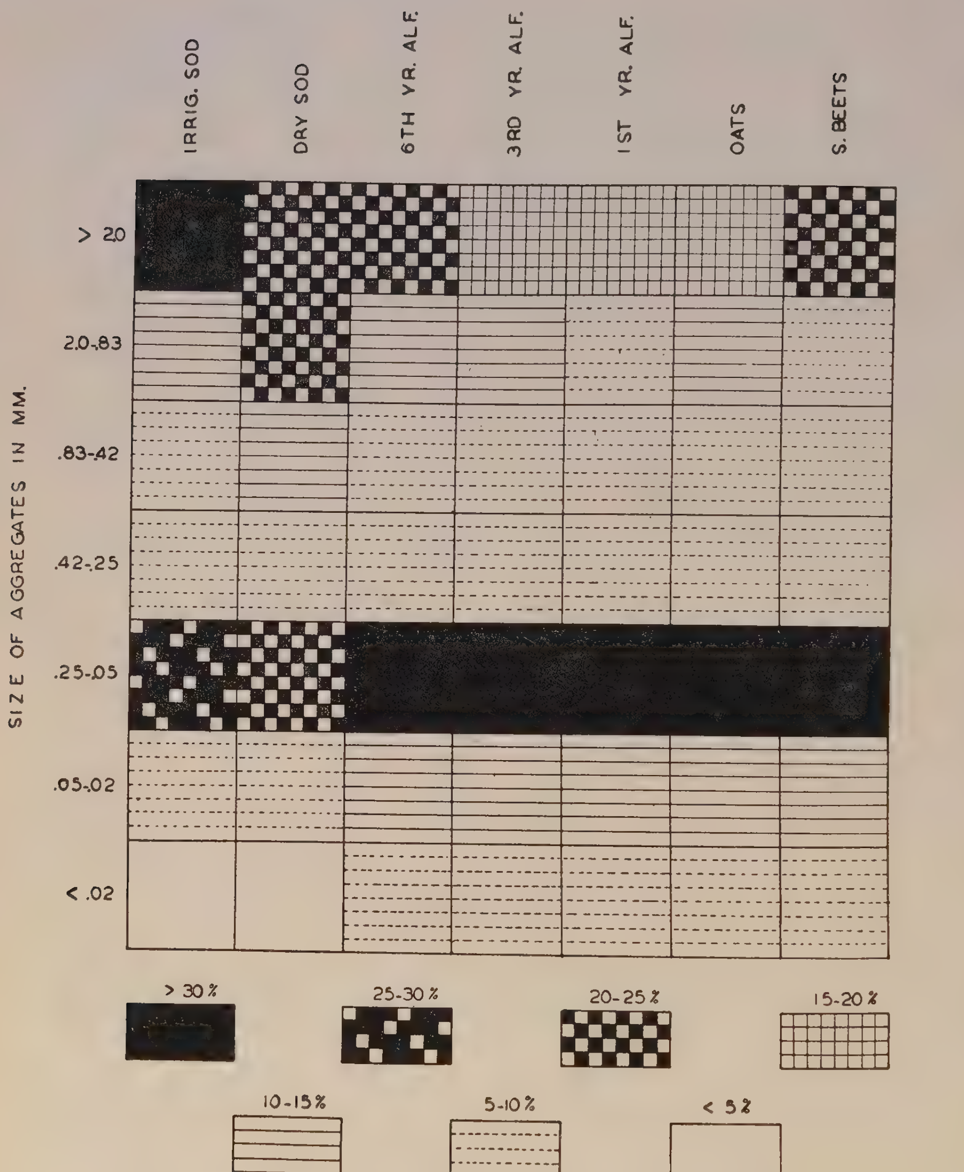

FIGURE 4. Percentages of water-stable aggregates of various sizes in several plots of a 10-year irrigated crop rotation and in two adjacent sod strips.

the plots. The value of 4.69 per cent for the sod compares very favourably with the figure of 4.62 per cent for 1910, calculated from Shutt's data and show in Table 2.

Physical Analyses of Soil

In 1950 physical analyses were made of samples of the soil from five plots of Rotation "U" together with samples from unirrigated sod in the railway right-of-way which forms the north border of the north plot and the irrigated

sod strip which forms the east border of all plots. The railway was built in 1885 and the right-of-way has been little disturbed since and now supports mainly native grass cover. The sod strip on the east of the plots regularly receives some irrigation water and supports a dense sod of Kentucky blue grass.

Figure 4 shows graphically the relative percentages of the different size fractions of water stable aggregates from the two sod areas and the five plots of Rotation "U".

Actually all plots have been maintained in good structure and tilth throughout the life of the rotation. As indicated by the high percentages of the larger aggregates, the soil of all plots showed excellent structure and stability, much superior to that usually experienced on intensively farmed irrigated land. The samples from the sod areas differed from those of the cultivated plots by exhibiting a higher percentage of aggregates in the larger fractions and lower percentages in the smallest fraction but the variations were not great. With one exception (the 2.0-0.83 mm. fraction) the plot growing sugar beets showed the same distribution of aggregate sizes as the sixth-year plot of alfalfa. Since next year this sugar beet plot will produce wheat, seeded down to alfalfa, it would appear that the stability of the soil structure remains quite constant over the complete rotation cycle.

SUMMARY

Yields and trends of yields over a 40-year period in a 10-year irrigated crop rotation situated on a typical Southern Alberta soil at the Dominion Experimental Station, Lethbridge, have been discussed.

While the native prairie soils have produced abundant yields under irrigation and usually are considered to be rich in plant nutrients, experience with this rotation indicates that applications of phosphate fertilizer and manure are essential to the maintenance of high yields, particularly of such crops as sugar beets and alfalfa.

Under a cropping practice, which included six years of alfalfa in a 10-year rotation, the nitrogen content of the soil was increased consistently over a 30-year period but now may be levelling off. The percentage of organic matter has decreased over a 40-year period. The physical structure of the soil has been maintained to a very satisfactory degree.

ACKNOWLEDGMENTS

Acknowledgment is made to W. H. Fairfield (retired), Superintendent of the Lethbridge Experimental Station from 1906 to 1945, who established the rotation. Dr. Fairfield also gave helpful advice during the preparation of the manuscript as did A. E. Palmer, present Superintendent of this Station. S. Dubetz, Graduate Assistant, assisted with the calculations and drawings and the soil analyses were carried out under the direction of J. L. Doughty, Soils Research Laboratory, Swift Current, Saskatchewan.

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THE ABILITY OF FORAGE PLANTS TO SURVIVE EARLY SPRING FLOODING[1]

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The ability of forage plant species to endure flooding is a matter of considerable interest and importance wherever periodic or seasonal inundations of land occur. Under these conditions, information regarding relative ability to survive various periods of flooding is desirable for determining species or mixtures to seed.

In Western Canada there are extensive areas of low-lying lands, subject to early spring flooding from snow run-off water. In their natural state, most of these areas support vegetation of the grass or sedge families, the dominant species usually being determined by the length of the flooding period. Some of these lands yield very little or produce low quality feeds. In other instances, adverse treatment such as overgrazing has brought about a replacement of native forage species with undesirable weeds. Production can often be greatly increased by seeding to perennial cultivated forage crops, but the species used must be able to endure the normal period of spring flooding which will occur.

Bolton and McKenzie (1) reported on the relative tolerance to flooding of eight grasses and legumes as determined by field experiments on irrigated land. They found that sweet clover withstood 9 to 12 days of early spring flooding; alfalfa 10 to 14 days; crested wheatgrass 10 to 17 days; brome 24 to 28 days; slender wheatgrass 31 to 35 days; meadow fescue 24 to 35 days, while timothy and Reed canary grass stood amounts in excess of 49 days. A subsequent paper by Heinrichs and McKenzie (3) dealt with the effect of different depths of water and various periods of flooding on emergence of Reed canary grass seed under greenhouse conditions. This study was undertaken to determine if Reed canary could be seeded in the late fall just prior to freeze-up on land that would be flooded the following spring, this period being the most desirable time to sow if sufficient plants would emerge after flooding to produce a stand. It was found that seed of Reed canary did not emerge under water but emergence commenced once the water was drained. Flooding for as long as 63 days significantly reduced emergence, but the number of seedlings emerging after this period of flooding was still considerable. These results prompted a further greenhouse study reported on by McKenzie, Anderson, and Heinrichs (4) and concerned the effect of flooding on emergence of a number of forage crop seeds. Seeds of 14 species were flooded for periods ranging from 3 to 12 weeks and emergence after flooding recorded. Legume seeds were able to endure only very short periods of flooding compared to most of the grasses. Some of the grasses whose seeds were able to endure flooding best were Reed canary, timothy, slender wheatgrass, Virginia wild rye, bromegrass, tall wheatgrass, meadow fescue, and meadow foxtail.

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Davis and Martin (2) placed turfs of several species and mixtures in ammunition tanks and flooded these at depths of water from one to six inches. Timothy, *Agropyron*, and meadow fescue survived ten weeks of flooding, meadow fescue showing greater resistance to flood damage than timothy, although the latter recovered more rapidly. Red fescue, ryegrass, and cocksfoot killed out readily when flooded four to eight weeks, the amount of damage increasing in severity the greater the depth of water. Meadow foxtail survived two months' flooding at all depths of water, while white clover was severely damaged after four or five weeks but survived where the leaves were held above water. Resistance to flood damage in this species seemed greater in winter before active growth commenced.

At Melle in Belgium, Reyntens (5) subjected a number of grass and legume species to approximately 98 days' flooding in specially constructed concrete tanks. The species were flooded in December and drained in March. It was found that legumes such as *Trifolium repens*, *Trifolium pratense*, and *Trifolium hybridum* had little resistance to flooding, whereas good resistance to flooding was exhibited by the following grasses: *Alopecurus pratensis*, *Poa trivialis*, *Phleum pratense*, and *Agrostis* sp. Grasses showing little resistance to flooding were *Lolium perenne*, *Lolium italicum*, and *Festuce pratensis*.

The present paper presents results from three field experiments conducted in 1949 and 1950 on the flooding tolerance of certain grasses and legumes. Experiment I dealt with the effect of early spring flooding on stands which had been established the previous spring. The objective was to obtain additional information on mature plant tolerance to flooding of various grasses and legumes not previously tested. Experiment II concerned the effect of early spring flood on plants in the seedling stage. Under conditions where early fall is an otherwise suitable time at which to seed, this information would indicate the species that could be seeded early in the fall if a specific period of flooding is expected in the spring. Experiment III was conducted to determine the effect of early spring flooding on seeds planted in the late fall just prior to freeze-up. Where late fall is otherwise the best seeding time, the results would indicate the periods of flooding which seeds of various species could endure and still emerge sufficiently to result in a satisfactory stand. This experiment was done also to corroborate results obtained in previous greenhouse experiments.

Of interest in all three experiments was the relationship between species in ability to stand flooding as mature plants, seedlings, and seeds.

MATERIAL AND METHODS

Experiment I—The Effect of Early Spring Flooding on Established Stands

The species included in this experiment were spring seeded in parallel strips 4 feet wide between border ditches 60 feet apart. The stands were irrigated as required during the year of establishment. In the fall, dikes were constructed at right angles to the crop strips, resulting in the formation of a number of basins which could be filled with water and drained independently. Each basin measured 25 feet by 60 feet and contained a 4 feet by 25 feet plot of each species in the experiment. These basins were flooded for periods of 7, 14, 21, 35, 49, and 63 days. The flooding treatments were in duplicate, hence there were a total of 12 basins.

As soon as it was possible to run water in the irrigation ditches the following spring, all the basins were filled with water to a depth of about 12 inches. This first flooding corresponded closely with the spring run-off period and was done on March 31 in 1949 and April 21 in 1950. The basins were drained according to their flooding treatments. Periodic reflooding was required to maintain the depth of water at 12 inches during the flooding periods since losses resulted from seepage and evaporation.

Following the flooding treatments, notes were recorded on the percentage of permanent injury on each plot as a result of flooding.

Experiment II—The Effect of Early Spring Flooding on Seedlings

This experiment was conducted in 1950 only. The procedure and design was the same as for Experiment I. The species used were again seeded in parallel strips four feet wide between border ditches. The seedings were made at the end of August and irrigated immediately to start germination. Later in the fall, dikes were built to form the flooding basins. The following spring, these basins were flooded at the same date and for the same periods of time as in Experiment I. Observational data on percentage of permanent injury were recorded following drainage.

Experiment III—The Effect of Early Spring Flooding on Emergence of Seeds

This experiment was conducted in 1949 and 1950, employing the same general procedure as in Experiments I and II. Seeding, again in parallel strips four feet wide, was done late in October when the weather became cold enough to prevent germination. Dikes were constructed to form the flooding basins after seeding. The flooding treatments in the spring of 1950 were the same as for Experiments I and II, but in 1949 the periods of flooding were for 14, 28, 42, and 56 days.

TABLE 1.—LIST OF SPECIES USED IN FLOODING EXPERIMENTS

Common name	Scientific name	Exp. I	Exp. II	Exp. III
Ladak alfalfa	*Medicago media* L.	x	–	x
White sweet clover	*Melilotus alba* Desv.	–	–	x
Altaswede red clover	*Trifolium pratense* L.	x	–	x
Alsike clover	*Trifolium hybridum* L.	x	–	x
Strawberry clover	*Trifolium fragiferum* L.	–	–	x
Intermediate wheatgrass	*Agropyron intermedium* (Host.) Beauv.	x	x	x
Slender wheatgrass	*Agropyron trachycaulum* (Link) Malte var. *typicum* Fern.	x	x	x
Tall wheatgrass	*Agropyron elongatum* (Host.) Beauv.	x	x	x
Fairway crested wheatgrass	*Agropyron cristatum* (L.) Gaertn.	–	x	–
Western wheatgrass	*Agropyron Smithii* Rydb.	x	–	–
Virginia wild rye	*Elymus virginicus* L. var. *submuticus* Hook.	x	x	x
Russian wild rye	*Elymus junceus* Fisch.	x	x	x
Beardless wild rye	*Elymus triticoides* Buckl.	–	–	x
Creeping red fescue	*Festuca rubra* L.	x	x	–
Meadow fescue	*Festuca elatior* L.	x	x	x
Common brome	*Bromus inermis* Leyss.	–	x	x
Reed canary	*Phalaris arundinacea* L.	–	x	x
Orchard grass	*Dactylis glomerata* L.	x	–	–
Timothy	*Phleum pratense* L.	x	x	x

Emergence after flooding was determined by making stand counts, from which percentage emergence was calculated.

The three experiments were conducted on adjacent border strips. The soil type is an alluvial clay loam containing slight amounts of saline salts at the surface and moderate concentrations in the lower horizons. Table 1 lists the species used and the experiment or experiments in which they were included.

RESULTS AND DISCUSSION

Experiment I—The Effect of Early Spring Flooding on Established Stands

The results obtained in this experiment for the two years are presented in Table 2.

TABLE 2.—ESTIMATED PERCENTAGE OF PERMANENT INJURY RESULTING FROM VARIOUS PERIODS OF EARLY SPRING FLOODING ON ESTABLISHED STANDS OF GRASSES AND LEGUMES

Species	Year	Percentage injury after flooding					
		7 days	14 days	21 days	35 days	49 days	63 days
		%	%	%	%	%	%
Altaswede red clover	1949	0	65	100	100	100	100
	1950	0	0	0	90	100	100
Ladak alfalfa	1949	0	0	40	90	100	100
	1950	0	0	0	90	100	100
Alsike clover	1949	0	0	35	75	100	100
	1950	0	0	0	85	100	100
Orchard grass	1949	0	10	90	100	100	100
	1950	0	0	15	100	100	100
Intermediate wheatgrass	1949	0	0	0	50	100	100
	1950	0	0	0	100	100	100
Creeping red fescue	1949	0	0	0	30	100	100
	1950	0	0	0	80	100	100
Tall wheatgrass	1949	0	0	0	0	75	100
	1950	0	0	0	10	50	80
Virginia wild rye	1949	0	0	0	10	70	100
	1950	0	0	0	0	45	75
Slender wheatgrass	1949	0	0	0	0	0	90
	1950	0	0	0	0	5	15
Meadow fescue	1949	0	0	0	0	55	100
	1950	0	0	0	0	0	10
Timothy	1949	0	0	0	0	0	70
	1950	0	0	0	0	0	5
Western wheatgrass	1949	0	0	0	0	0	55
	1950	0	0	0	0	0	15
Russian wild rye	1950	0	0	0	100	100	100

Two points stand out clearly. First, great differences exist between species in tolerance to flooding. As a group, grasses stood much more flooding than legumes. Among the grasses, large differences are also apparent, orchard grass being least tolerant and timothy and western wheatgrass standing very long periods of flooding before exhibiting any injury. The second point of interest is the differences in tolerance to flooding of the same species in the two years. Thus it will be observed that red clover suffered 65 per cent injury in 1949 after 14 days' flooding but no injury in 1950 following this period of flooding. Similarly, meadow fescue was injured 55 per cent by 49 days' flooding in 1949 but was uninjured in 1950 after this length of time. All other species show the same relationship, with the exception of intermediate wheatgrass and creeping red fesuce which were injured to a greater extent in 1950 than in 1949.

In an attempt to explain why these differences in tolerance to flooding may have occurred, temperature records for the flooding period in both years were consulted. These records are given in Table 3.

The flooding period in 1950 started three weeks later than in 1949, but despite this fact mean temperatures at comparable periods of flooding were much lower in 1950 than in 1949. These rather great differences suggest that temperature may be an extremely important factor in determining the amount of flooding a particular species is able to endure. At colder temperatures, plants would tend to remain dormant longer and their oxygen requirements would be less than when growth commenced. It is a common observation that most species are rather easily killed out by short periods of flooding during mid-summer when high temperatures prevail.

On the basis of the data obtained for these two years, Table 4 was compiled to indicate the range in flooding tolerance of the various species. This table shows the range in days from the time at which little or no injury occurred up to the time at which complete or very severe injury resulted. Thus, the experiment indicated that red clover will stand 7 days' flooding but may be completely killed out by 14 days' flooding or somewhere between 7 and 14 days. Similarly, tall wheatgrass is unlikely to be damaged by 35 days' flooding but may suffer considerably between 35 and 49 days of flooding.

It is of interest to compare these results with those secured in earlier studies (1). Four species, alfalfa, slender wheatgrass, meadow fescue, and timothy, were included in both investigations. The previous work indicated

TABLE 3.—MEAN TEMPERATURES DURING THE FLOODING PERIODS IN 1949 AND 1950

Number of days flooded	Temperatures in ° F.		
	1949	1950	Difference
7	42.6	36.2	6.4
14	45.4	36.0	9.4
21	47.1	39.0	8.1
35	48.9	44.0	4.9
49	51.4	46.8	4.6
63	52.1	50.0	2.1

TABLE 4.—SPRING FLOODING TOLERANCE RANGE OF ESTABLISHED GRASSES AND LEGUMES

Species	Number of days
Red clover	7-14
Alfalfa	14-21
Alsike clover	14-21
Orchard grass	14-21
Intermediate wheatgrass	21-35
Russian wild rye*	21-35
Creeping red fescue	21-35
Tall wheatgrass	35-49
Virginia wild rye	35-49
Slender wheatgrass	49-63
Meadow fescue	35-63
Timothy	49-63
Western wheatgrass	49-63

* Based on one year's results.

that alfalfa would stand 10 to 14 days' flooding whereas, in the present experiment, the suggested range is 14 to 21 days. The range for slender wheatgrass was given as 31 to 35 days and as 49 to 63 days in the 1949-1950 experiment; while meadow fescue was 24 to 35 days compared to 49 to 63 days. In the previous experiments, timothy survived 49 days' flooding, the longest period that it was flooded, and in this recent experiment the range was 49 to 63 days. The variation in results secured with the first three species in these two investigations which were conducted several years apart on very different soil types and at different locations, plus the inter-year variations found in both studies, point out the fact that tolerance to flooding cannot be defined accurately within specified periods of time. Temperature, soil type, depth of water, and age of the stand may all influence the length of flooding which a species may endure. However, it is felt that the results do indicate the general relationship which exists between species in tolerance to flooding. Within the same general climatic zone where these results were obtained, they will be useful as a guide to selection of species to use on land subject to early spring flooding if the approximate duration of the flooding period is known.

Experiment II—The Effect of Early Spring Flooding on Early Fall Established Seedlings

The data for this experiment which was conducted in 1950 are presented in Table 5.

Although the results are for the one year only, the same general relationship is evident between species in flooding tolerance at the seedling and mature plant stages. It will be seen that several species were able to stand about the same amount of flooding in Experiment II as in Experiment I. On the other hand, some species were less tolerant of flooding in the seedling stage than when they were mature plants.

TABLE 5.—ESTIMATED PER CENT INJURY FROM EARLY SPRING FLOODING TO SEEDLINGS ESTABLISHED IN THE EARLY FALL

Species	Percentage injury after flooding					
	7 days	14 days	21 days	35 days	49 days	63 days
	%	%	%	%	%	%
Intermediate wheatgrass	0	0	55	100	100	100
Crested wheatgrass	0	0	0	100	100	100
Creeping red fescue	0	0	15	100	100	100
Russian wild rye	0	0	0	100	100	100
Timothy	0	0	0	100	100	100
Tall wheatgrass	0	0	0	85	100	100
Virginia wild rye	0	0	0	85	100	100
Slender wheatgrass	0	0	0	75	100	100
Reed canary	0	0	0	0	100	100
Meadow fescue	0	0	0	0	0	100
Brome	0	0	0	0	5	100

TABLE 6 —PERCENTAGE EMERGENCE OF LATE FALL SEEDED GRASS AND LEGUME SEEDS AFTER VARIOUS PERIODS OF EARLY SPRING FLOODING, 1949

Species	Percentage emergence after flooding				
	Check	14 days	28 days	42 days	56 days
	%	%	%	%	%
Ladak alfalfa	100	37	5	0	0
Intermediate wheatgrass	100	21	23	31	12
Brome	100	42	37	59	39
Reed canary	100	40	59	102	56
Slender wheatgrass	100	55	55	44	36
Meadow fescue	100	59	85	36	17
Timothy	100	60	55	98	67
Beardless wild rye	100	63	97	101	10
Virginia wild rye	100	78	155	172	88
Tall wheatgrass	100	84	75	66	39

Experiment III—The Effect of Early Spring Flooding on Emergence of Seeds Planted in the Late Fall

The data from this experiment are presented in Tables 6 and 7 which give the 1949 and 1950 results, respectively.

In Table 8, the two years' results have been summarized to indicate the range in days that seeds of the various species could endure and, following which, emergence was still enough to produce satisfactory stands.

It is of interest to compare these conclusions with those arrived at in similar experiments in the greenhouse (4). Seed of practically all species was unable to endure flooding as long in the field as it did in the greenhouse. Some possible explanations for this fact were observed during the field experiment. Flooding, and particularly the longer flooding periods, caused puddling of the soil and after drainage a very hard crust formed as the soil dried out. Undoubtedly, this crust formation reduced emergence. In some of the longer flooding treatments, salts were brought to the surface and this condition would reduce germination, especially of those species

not particularly tolerant to salinity such as timothy, Reed canary, red and alsike clover. Weather conditions prevailing after drainage at about the time when the soil became dry enough to allow germination seemed to influence the resulting emergence. Hot, dry weather would produce more severe crusting and lower emergence, whereas cooler conditions or a shower of rain to soften the crust would permit higher emergence. Some of these factors need to be considered when studing the data, particularly where emergence is greater from one flooding treatment than from the previous treatment of shorter duration.

TABLE 7—PERCENTAGE EMERGENCE OF LATE FALL SEEDED GRASS AND LEGUME SEEDS AFTER VARIOUS PERIODS OF EARLY SPRING FLOODING, 1950

Species	Percentage emergence after flooding						
	Check	7 days	14 days	21 days	35 days	49 days	63 days
	%	%	%	%	%	%	%
Altaswede red clover	100	0	0	0	0	0	0
Sweet clover	100	62	2	0	0	0	0
Ladak alfalfa	100	50	12	12	0	0	0
Alsike clover	33	100	0	8	0	0	0
Strawberry clover	0	100	33	35	0	10	15
Intermediate wheatgrass	100	0	11	17	4	4	0
Russian wild rye	50	0	27	100	18	0	0
Meadow fescue	100	7	26	33	7	0	0
Timothy	0	32	100	57	3	1	0
Reed canary	0	100	44	88	77	11	0
Tall wheatgrass	0	62	50	100	50	0	0
Brome	88	0	60	53	100	0	0
Beardless wild rye	22	11	44	100	44	22	0
Virginia wild rye	29	6	60	100	53	18	0
Slender wheatgrass	40	100	100	90	60	10	0

TABLE 8—FLOODING TOLERANCE RANGE OF GRASS AND LEGUME SEEDS

Species	Number of days
Red clover*	0- 7
Sweet clover*	7-14
Alfalfa	7-14
Alsike clover*	7-14
Strawberry clover*	7-21
Intermediate wheatgrass	21-28
Russian wild rye*	21-35
Meadow fescue	21-42
Beardless wild rye	35-42
Brome	35-56
Reed canary	35-56
Slender wheatgrass	35-56
Timothy	21-56
Virginia wild rye	35-56
Tall wheatgrass	35-56

* Based on 1950 results.

TABLE 9.—RANGE IN DAYS FOR TOLERANCE TO EARLY SPRING FLOODING OF GRASSES AND LEGUMES AS MATURE STANDS, SEEDLINGS, AND SEEDS

Species	Mature plants	Seedlings	Seeds
	days	days	days
Altaswede red clover	7-14	—	0- 7
Alfalfa	14-21	—	7-14
Sweet clover	10-14*	—	7-14
Alsike clover	14-21	—	7-14
Strawberry clover	—	—	7-21
Orchard grass	14-21	—	—
Intermediate wheatgrass	21-35	14-21	21-28
Russian wild rye	21-35	21-35	21-35
Creeping red fescue	21-35	21-35	—
Tall wheatgrass	35-49	21-35	35-56
Virginia wild rye	35-49	21-35	35-56
Slender wheatgrass	49-63	21-35	35-56
Meadow fescue	35-63	49-63	21-42
Timothy	49-63	21-35	21-56
Western wheatgrass	49-63	—	—
Reed canary	49 +*	35-49	35-56
Brome	24-28*	49-63	35-56
Crested wheatgrass	10-17*	21-35	—
Beardless wild rye	—	—	35-42

* Based on earlier experiments (1).

Although seeds did not endure nearly so much flooding in the field as in the greenhouse, the same general relationship between species was found to hold. Legume seeds do not stand very long periods of flooding before seed viability is greatly reduced, while seed of many of the grasses has very good ability to endure flooding. Among the grasses, the ranking in order of ability of seeds to stand increasing periods of flooding was about the same as determined in the greenhouse.

In Table 9, the three phases of this investigation have been summarized. This table brings out the fact that species which stand flooding best as mature plants also have the best ability to stand flooding in the seedling and seed stages. Tolerance to early spring flooding appears to be an inherent characteristic of forage plant species. These results show that a rather constant relationship exists between species in ability to stand flooding but the exact limits will probably vary a great deal under different climatic and soil conditions.

Under similar soil and climatic conditions, the information secured in this investigation can be used as a guide in the selection of forage crops to use on spring flooded lands, providing information is at hand as to the approximate duration of the flooding period on a given location. If late fall seeding just prior to freeze-up is the seeding date at which best stands are likely to result, then the ability of seeds to stand flooding would need to be considered. Similarly, if early fall seeding was the best time to seed, then seedling tolerance would have to be taken into account.

SUMMARY

Field experiments on irrigated land were conducted at Swift Current, Sask., to determine the ability of several grasses and legumes to endure varying periods of early spring flooding. The flooding treatments were

carried out on plants established the previous spring, on seedlings established in the early fall, and on seeds planted in the late fall just prior to freeze-up. The results showed a fairly constant relationship in tolerance to flooding among the various species at the three stages and indicated that ability to stand flooding is an inherent characteristic. At all three stages, grasses endured much more flooding than any of the legumes. The grasses able to stand the longest flooding periods were *Phalaris arundinacea*, *Phleum pratense*, *Agropyron Smithii*, *Festuca elatior*, *Agropyron trachycaulum* var. *typicum*, *Elymus virginicus* var. *submuticus*, *Agropyron elongatum*, and *Bromus inermis*. Grasses exhibiting lesser tolerance to flooding were *Agropyron intermedium*, *Agropyron cristatum*, *Elymus junceus*, *Festuca rubra*, and *Dactylis glomerata*. Differences in flooding tolerance between years, between field and greenhouse experiments, and between those secured in a previous investigation are discussed. Under similar soil and climatic conditions, the results can be used as a guide in the selection of suitable forage crops for low-lying lands subject to early spring flooding.

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EFFECT OF 2,4-DICHLOROPHENOXYACETIC ACID VAPOUR ON TOMATO PLANTS IN A GREENHOUSE[1]

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During September, 1948, the Laboratory of Plant Pathology was asked to locate the cause of serious trouble affecting a large planting of tomatoes in a greenhouse of the Parks Department, City of Edmonton. According to the evidence obtained, the injury was caused by fumes of 2,4-dichlorophenoxyacetic acid, accidentally spilt by employees in the rooms adjoining the greenhouse and not reported. The abnormal effects produced on tomato plants by toxic concentrations of 2,4-D have been described already by several investigators, and, therefore, no attempt is made to elaborate on them in this brief report.

Some of the symptoms exhibited by the tomato plants under existing conditions, as well as the method used to locate the source of contamination of the air of the greenhouse, will be of general interest.

SYMPTOMS

A view of the affected tomato plants on October 21 is presented in Figure 1, A. The older foliage was distorted but not chlorotic. The plants nearest the head-house door had more severe symptoms than those at the opposite end of the greenhouse. The lobes of many of the leaves were more or less deformed with uneven growth and the leaf-blade was often curled and fairly stiff (Figure 1, C). On some severely affected plants, there was hyperplastic growth of tissue at the nodes around the leaf petiole, and in some plants this growth also appeared in longitudinal strips between the nodes (Figure 1, B). Apparently the rate of growth of the plant was about normal. The terminal growth was more severely deformed than that lower on the stalk. The root system seemed normal and well developed.

Apart from additional growth, the plants presented essentially the same general appearance on November 25 as they had on October 21. The new growth at the top or sides of the plants appeared normal for a few days and then gradually became deformed. The flower clusters had emerged, or were emerging, from the axils. The top fruit branches were sterile (Figure 1, D). The lower ones were fertile, although their fruit was very undersized, uneven, and much more pointed than normal for the variety, Sutton's Best. Some of the branches half-way up the stalk bore clusters of small pointed fruit (Figure 1, E). On a number of the fruits there were green and ripe patches (Figure 1, G). Under these green patches, the elements of the vascular ring were brown, but invariably they became normal in colour again as the green patch turned red (Figure 1, F). Possibly this abnormality is a symptom of a nutritional disturbance produced by toxic fumes of 2,4-D (1).

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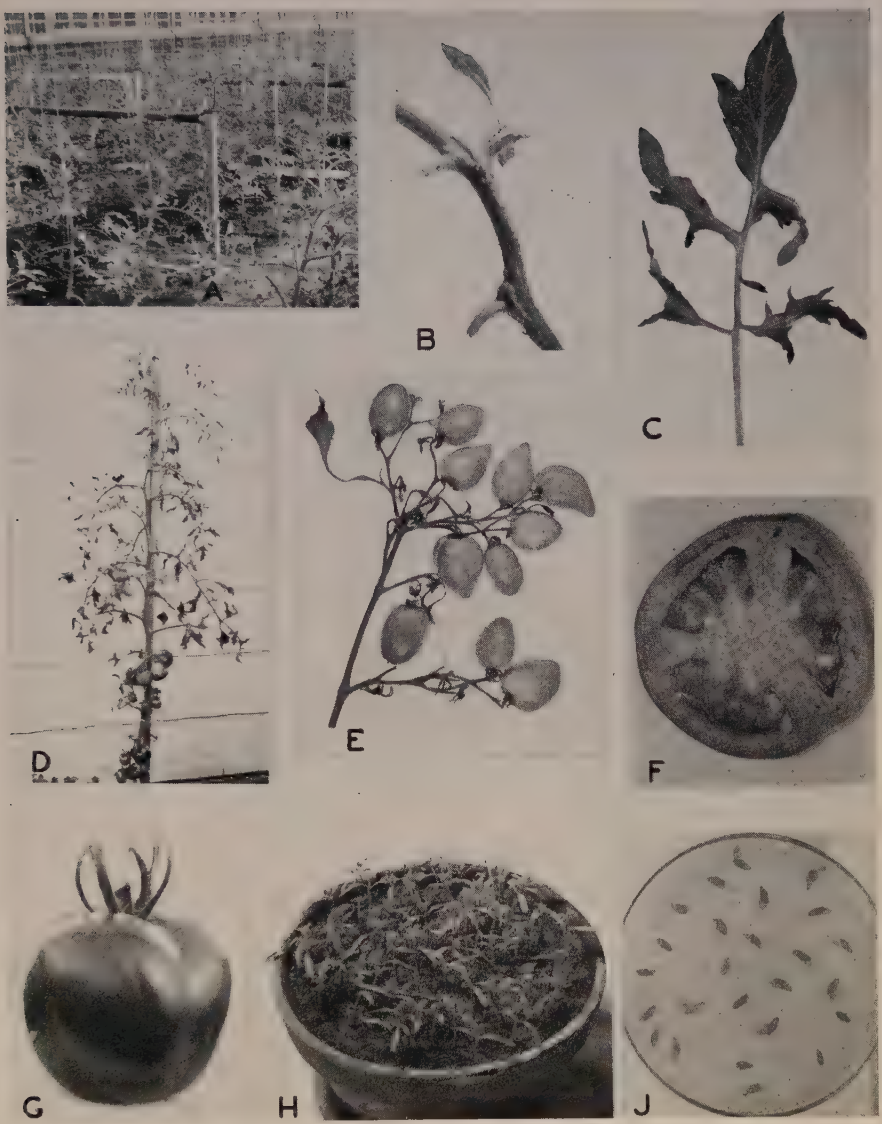

FIGURE 1. Tomato plants and fruit showing distortion produced by fumes of 2,4-dichlorophenoxyacetic acid in a greenhouse at Edmonton.

A. General view of affected plants, eight weeks old, in greenhouse.

B. Hyperplastic growth on stem, mainly at nodes.

C. Distortion of leaf.

D. Lower fruit branches were fertile, with fruit undersized and rough, but most branches higher on stem were sterile.

E. Undersized and pointed fruit on branch from mid-stem region.

F. Brown areas of general vascular region under green patches on fruit.

G. Undersized fruit having prominent green area surrounded by ripe area.

H. Terminal distorted leaves of young test plants exposed in affected greenhouse.

J. Cucumber seed, wet with an aqueous test-sample of air from the repair room impregnated with fumes of 2,4-D, showing failure to germinate normally.

EXPERIMENTAL

With a view to delimiting the cause of the trouble, preliminary tests were made to determine whether or not the seed, the soil, or a virus was involved.

Seed

Normal tomato plants were produced in the laboratory greenhouse from the same lot of seed as that from which the abnormal plants originated. Consequently, it was decided that the trouble was not seed-borne.

Soil

Tomato seed was sown in the laborarory bin soil and also in soil taken from the soil bin of the affected greenhouse. Three pots from each lot of soil were kept in the laboratory greenhouse and an equal number were taken to the affected greenhouse for observation. Plants in both soils kept at the laboratory greenhouse developed normally, whereas those in the pots taken to the affected greenhouse developed the characteristic abnormal symptoms within about 15 days. The results of this preliminary test strongly suggested that the presence of some toxic material or gas in the City of Edmonton greenhouse was the cause of the deformity of the tomato plants.

Virus

The possibility of the malady being caused by a virus (3) transferred by an insect vector, such as the white fly, was considered. A few white flies (*Trialeurodes vaporareorium* Woodw.) were present in the affected greenhouse, but a comparatively large number of them were also present in the laboratory greenhouse and very active, especially on the under-side of the leaves of *Datura* sp. and tomato. However, since no symptoms developed on tomato plants in the laboratory greenhouse, the possibility of this vector being involved was not considered further.

Snapdragon plants, about 8 to 10 inches high, in the affected greenhouse, exhibited severe curling, particularly of the apical leaves. Accordingly, scion-grafts were made from these diseased snapdragon plants, and also from the affected tomato plants, to healthy plants of *Datura stramonium*, tomato, and snapdragon. The scions lived in these grafted plants, but there was no development of the symptoms under investigation. Similar grafts were also made on *Nicotiana glutinosa*, *N. tabacum*, *N. rustica*, and *Solanum nodiflorum*, with negative results. Therefore, it seemed that the malady under discussion was not of a virus nature and that the causal agent was not transferred by grafting or by the white fly.

METHODS OF LOCATING THE SOURCE OF 2,4-D CONTAMINATION OF AIR OF GREENHOUSE AND ADJOINING ROOMS

Early in February, young, healthy tomato seedlings that were placed in the affected greenhouse soon developed the characteristic symptoms of the malady, as shown in Figure 1, H. These tomato plants gradually became normal again when they were exposed in the greenhouse of the laboratory. On the basis of this evidence, it was suspected that the air of the greenhouse was contaminated with 2,4-D. Accordingly, aqueous test-samples of the air in the head-house, the repair room, and the greenhouse,

were obtained. A leachate sample of the soil used was also included. The samples were secured by pumping air through 50 ml. of distilled water for 10 minutes. Tests of these samples for presence of 2,4-D were completed on germinating cucumber seeds, according to the method described by Ready and Grant (2). About 10 ml. of each water sample was used to moisten the filter paper on which 25 cucumber seeds were germinated. The presence of toxic amounts of 2,4-D in each of the samples was indicated by the extent to which root growth was suppressed in the cucumber seedlings.

According to the data obtained from these tests, a very toxic concentration of fumes of 2,4-D was present in the air of the repair-room at the time the sample was taken. This room adjoined the north greenhouse, and there were wide cracks in the board partition. The cucumber seed moistened with the sample from this room practically failed to germinate and gave an average root growth of about 2 mm. (Figure 1, J). Results from the samples taken from the south greenhouse permitted good growth of about 62.6 mm., but apparently the air in the north greenhouse, which was just off the repair room, was somewhat toxic, and permitted an average root growth of the germinating cucumber plants of 42.0 mm. There was no evidence of 2,4-D in the soil, since the root growth of the cucumber seedlings for the leachate test was about 72.2 mm. The root growth for seedlings of the distilled water control was about 70.1 mm., and for the 1 : 50,000 solution of 2,4-D control it was 15.2 mm. It must be remembered that the concentration of the fumes in the various rooms might vary at different times, according to the ventilation given these rooms or greenhouses before the samples were taken.

At this point in the investigation, it was learnt that 2,4-dichlorophenoxyacetic acid had been spilt accidentally from a bench in the greenhouse about ten months before the foregoing tests were made.

During October, 1949, about seven months later, the Superintendent, Parks Department, City of Edmonton, informed the investigators that the new crop of tomato plants in the city greenhouse was again showing symptoms of 2,4-D injury, and asked them to locate, if possible, the contaminated portion of the floor so that it could be removed or treated.

The problem was to identify the extent of the wooden floor then affected by the 2,4-D spilt there about 17 months earlier. Splinters of the wood from the floor, each weighing about one gram, were removed in east, west, north, and south directions at intervals up to a distance of six feet from the point where the 2,4-D was reported to have been spilt. Each of the wood samples was soaked for about 18 hours in 50 ml. of distilled water, and then 10 ml. from each sample was taken to moisten each of a number of cucumber seed samples placed on filter paper for the germination and root development tests. The average root growth of each sample was recorded at the end of three days. Briefly stated, the average root growth was only 6 mm. for the seed tested with the water taken from the floor where the 2,4-D was said to have been spilt. The average growth of roots for the floor samples taken two feet east and west was 12 and 15 mm., respectively, and 12 and 40 mm. for those samples taken two feet north and south, respectively. At four-, five-, and six-foot distances in all four

directions, the average growth was 60 mm., as compared to 58 mm. for the control (cucumber seeds moistened with distilled water). Apparently 2,4-D was not present in toxic amount at four feet from where it was spilt 17 months before these tests were made, but it was definitely toxic at two feet and less. The results of these tests were sent to the Parks Superintendent, who had the contaminated section of the floor replaced.

SUMMARY

Serious damage to tomatoes and certain other plants in a greenhouse was caused by 2,4-dichlorophenoxyacetic acid fumes emanating from an adjoining room. The source of the contamination of the greenhouse air was located by the precise yet simple method of germinating cucumber seeds moistened with water samples secured from different parts of the greenhouse building.

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